To My Mother

John C Shedd

July 9 1909

SHOP TESTS

ON

ELECTRIC CAR EQUIPMENT

FOR INSPECTORS AND FOREMEN

BY

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AND

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PREFACE.

This book is the first of two books designed to cover in a practical manner the testing of electric car equipment with such instruments and other facilities as may be available or obtainable in a car house. An effort is made to so present the subject that the instructions and information given can be profitably used even if not entirely understood. To this end simple explanations, illustrations and practical examples are freely used. The appended questions, it is believed, will efficiently rehearse the readers' knowledge of the information contained in the text. In the methods given refinement is at times sacrificed to practicability with the object of showing how results are obtained rather than how they might be. As the subject covers new ground, at least in the method of presentation, the writers feel that suggestions from readers would be especially valuable and invite the readers' cooperation.

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CONNECTIONS.

1. To measure current with an ammeter, connect the meter in series* with the circuit in which the current is to be measured:—thus to measure the current of a series motor or dynamo, connect in at *X*, *Y* or *Z*, Fig. 1; as this is a simple series circuit the current in all parts is the same. In a shunt

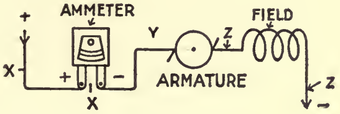

FIG. 1.

dynamo the current divides between the external and field circuits; in a shunt motor, between the armature and field circuits; in either case to measure: (*a*) total current, connect the meter at *X*, Fig. 2; (*b*) armature current, at *Y*; field current, at *Z*. Never break the circuit at the meter and be certain that the meter + post connects to the

* See articles 20 and 21.

+ side of the circuit, to avoid slamming the needle to the wrong side of 0. In no case must the meter be subjected to current exceeding its rating; such currents cannot be read and are liable to injure the instrument. Ammeter resistance is so low that its insertion in a circuit has a negligible effect.

Reading Large Currents.

2. Two Ammeters in Parallel. Currents exceeding the rating of a single meter can be indicated on two meters in parallel, provided their

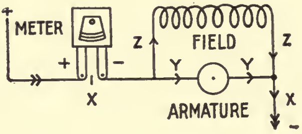

Fig. 2.

relative resistances are such that the current divides between them proportionally; otherwise one needle will be thrown off the scale and the other indicate less than it should. For two meters, A and B, to indicate current equal to the sum of their ratings, the resistance of A must be as many times that of B as the current rating of B is times that of A. For a 50-ampere meter and a 150-ampere meter to indicate 200 amperes, the resistance of the 50-ampere meter must be 3 times that of the 150-ampere meter. Proportional sharing of current between such small resistances can be effected better by experiment than calculation, because the resistance of a poor connection can easily exceed that of the meter. Current division between parallel meters is actually effected by varying the binding screw pressures on them and it will be necessary to do this even when the meters have equal resistances and ratings. A better way is to increase the length of the leads of the meter that takes more than its part; thus in Fig. 3, if meter *A* takes more than its share, loosen its bind-

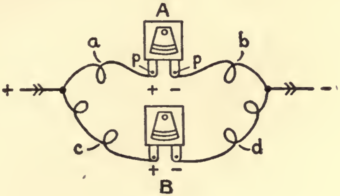

Fig. 3.

ing screws and tighten those of *B*; or lengthen leads *a* and *b* or shorten *c* and *d*. These devices are permissible in testing, but not as permanent connections, for they waste energy and cause heating that might eventually start a fire.

3. Shunting an Ammeter. The rating of an ammeter can be increased by a *shunt* adjusted to take a known part of the current; thus if a meter has in parallel with it, a resistance equal to its own, each will take half the current: when using this shunted meter to indicate current, every reading must be multiplied by 2 to get the total current; here 2 is called the *constant* and it applies to only this particular shunt adjustment.

4. With a second meter it is easy to adjust a shunt to any shunting power. Thus in Fig. 4, the difference in the readings of meters A and B, is the current in shunt S; if A indicates 100 and B, 25 amperes, the current in S is $100 - 25 = 75$ amperes. As the meter shunted indicates but a quarter of the total current, the constant or multiplier is 4. In all cases the constant to be used

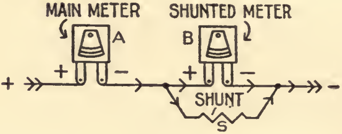

Fig. 4.

in a shunt-ammeter-adjustment can be obtained by rule 1.

Rule 1. To get the constant of a shunted ammeter, *divide the total current by the current in the shunted meter.*

Example 1. With a main current of 150 amperes, the shunted ammeter reading is 50 amperes. What is the constant and how is it to be used?

Solution 1. By rule 1, $150 \div 50 = 3$, constant; when measuring currents, every reading must be multiplied by 3 to get the total current.

5. Where no main current ammeter is available, adjustment on a circuit of variable voltage is tedious, but can be made with the connections of Fig. 5. Here R is a variable resistance; A, the meter, to be shunted and S is the shunt, including switch K for cutting it in and out. With K open, A indicates total current; with K closed, S takes part of the current. The length of lead X can be varied by drawing it through post p. To make an adjustment, open K and adjust the current to a value less than the rating of A; then repeatedly close K, loosen post p, change the length of X or

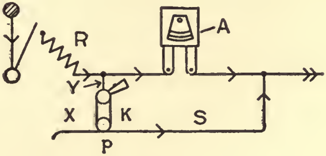

FIG. 5.

Y, tighten p and open K, until the deflection with K open is 2, 3 or 4 times that with it closed. As a rule the constant is made 2, the length of X being changed until closing K halves the reading of ammeter A.

6. Where the meter is wanted for but few readings it is unnecessary, to get a whole-number constant. For example, if, on closing K the first time, the deflection falls from 150 to 62 and trials show this relation to be correct, then the constant, 2.419 ($150 \div 62 = 2.419$) could be used. For a great number of readings the labor of multiplying by this fractional constant would be so great as to warrant a whole number.

Notes. Conductors X and Y should be of the largest size to be easily drawn through post p, otherwise the current is liable to heat them and thereby change the resistance and alter the constant.

A shunt adjusted for one meter will have a different constant when used with another. Constants must in each case be found by trial.

VOLTMETER RESISTANCE METHOD.

7. To measure current with a voltmeter and known resistance, connect the resistance in series with the conductor in which current is to be measured and in parallel with the voltmeter. Take a reading and apply rule 2.

Rule 2. To calculate current from the drop across a known resistance, *divide the drop across the known resistance by the resistance.*

Example 2. The current taken at full speed on level track and a voltage of 550, by a 21-ton car equipped with four 50-hp. motors must be measured with a voltmeter and a known resistance. How can it be done?

Solution 2. In series with the overhead switch or circuit-breaker, connect a 50-hp. railway motor field coil to be used as a standard resistance, R, Fig. 6, and in parallel with the coil connect a switch K, to be closed except when taking a reading;

connect the voltmeter across the standard coil. Let the car reach full speed, open *K* and take a reading. Assume the standard field coil to measure 0.035 ohm and the drop across it to be 5.25 volts, apply rule 2:

$$5.25 \div 0.035 = 150 \text{ amperes.} \quad \textit{Ans.}$$

Notes. Without *K*, *R* will get hot, its resistance and drop will increase and indicate more current than exists. Without *K*, *R* must be measured after each reading and this value used in the cal-

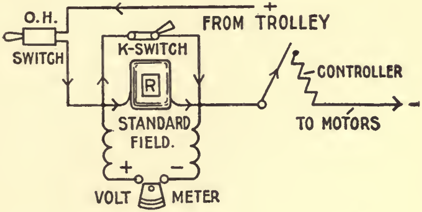

FIG. 6.

culation. If only the approximate current is wished, take the drop in one of the car motor field coils, the approximate resistance of which is known, and apply rule 2 to get the current of one motor; this multiplied by the number of motors is approximately the total current taken by the car.

To get close results, *R* should be a standard resistance not much affected by temperature changes. The voltmeter should be low reading so that a small drop will give a large deflection.

Example 3. The field resistance of a shunt-wound shop motor is 125 ohms cold and 140 ohms hot; on a 500 volt line what is the field current: (*a*) when the motor is first started? (*b*) after the field windings are hot?

Solution 3. (*a*) Field current at start $= 500 \div 125 = 4$ amperes. *Ans.* (*a*).

(*b*) Field current after a run $= 500 \div 140 = 3.57$ amperes. *Ans.* (*b*).

WATTMETER METHODS.

Wattmeter.

8. A wattmeter shows the instantaneous value of the rate at which energy is absorbed in the circuit with which the meter is connected. As it indicates the product of volts and amperes, *i.e.*, watts, if its indication be divided by the volts, the result will be the amperes.

Rule 3. To measure direct current with an indicating wattmeter, connect its series coil in series with the conductor in which current is to be measured and apply a known voltage to the shunt coil. *Divide any watt reading by the known voltage and the result is the current.*

Example 4. The current of a 25-hp. motor driving mill shafting is to be measured; the source of standard voltage is 28 storage cells (60 volts total voltage) ordinarily used to operate multiple-unit train-control circuits. Apply a wattmeter to this test.

Solution 4. Connect the wattmeter series coil in series with the motor circuit, as in Fig. 7, and the shunt coil across the battery. Close K and K' and read the meter; calling the reading 1,200, by rule 3.

$$1{,}200 \div 60 = 20 \text{ amperes.} \quad \textit{Ans.}$$

Note. As the meter indication depends on the product of the volts and amperes to which the meter is subjected, the reading will be lower than if the meter were so connected as to indicate the

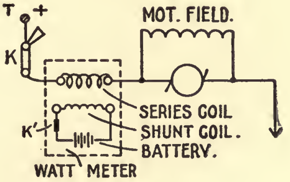

FIG. 7.

power of the motor, because the battery voltage is less than the voltage across the motor terminals.

WATT-HOUR METER.

9. A watt-hour meter (often erroneously called recording or integrating wattmeter) shows the watt-hours of energy absorbed in the time the record is taken. Dividing this watt-hour record by the time in hours or fractions of an hour gives the average absorption rate or power in watts.

Rule 4. To measure current with a watt hour meter, *divide the meter record by the time in hours, then by the known voltage acting.*

Example 5. Apply a watt-hour meter to the measurement in example 4.

Solution 5. Connect the meter as in Fig. 7, the known voltage being connected to the meter armature; take a reading, close K and K' and let the meter run for 10 minutes ($\frac{1}{6}$ hour), then open K and K' and take the reading. Subtract the first reading from the second to get the watt-hours, in this particular case 200, and apply rule 4:

$$200 \div \tfrac{1}{6} = 1{,}200$$

and $$1{,}200 \div 60 = 20 \text{ amperes.} \quad \textit{Ans.}$$

Note. Ordinarily a watt-hour meter gives no information as to the voltage and current acting on it but gives their product multiplied by time. Sometimes it is interesting to know the average current of the test; this can be gotten from an ammeter connected in series with the watt-hour meter or by taking periodical readings of a voltmeter in parallel with it, then dividing the watt-hour meter record in watts by the average voltage. Where a circuit has fairly constant voltage, the average current can be approximated by dividing the watt-hour record by the voltage.

VOLTAGE MEASUREMENTS.

VOLTMETER METHOD.

CONNECTIONS.

10. To measure voltage or potential drop (p.d.) with a voltmeter, connect lines from the meter to the points between which the p.d. is to be read, the + post of the meter being connected to the + side of the circuit. In Fig. 8, if the volt-lines be touched to *T* and *G*, the meter will indicate line voltage; if touched to *T* and *a*, the p.d. in resistance *R* 1 will be indicated; contact with *a* and *b*

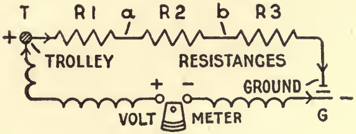

FIG. 8.

will show the p.d. in *R* 2 and so on. With 5 lamps in series across 550 volts, as in Fig. 9, the p.d. in any lamp is indicated by applying the volt-lines across the terminals of that lamp. Such a test will show the drop to vary from lamp to lamp because the resistance per lamp varies. Standing on the ground and touching the + side of lamp 5 will give a shock due to the p.d. in one lamp—about 110 volts; on touching the ground and the +

side of lamp 4, the shock will be due to the drop in 2 lamps—220 volts, and so on, contact with the ground and + side of lamp 1 giving a shock due to the p.d. in 5 lamps—line voltage.

11. The resistance of a voltmeter is high, and its current small. When used to indicate the voltage across an open circuit, as in Fig. 10, the meter bridges the gap and there is a current; but the current is negligibly small. The voltmeter so placed is in series with the rest of the circuit, but the meter resistance is comparatively so great

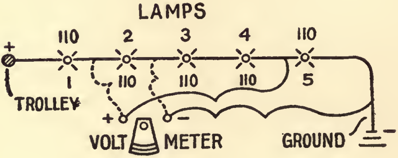

FIG. 9.

that practically the total p.d. takes place across it. In connecting a voltmeter to indicate the drop in a resistance, as in Fig. 6, the meter is in parallel with the resistance in which the drop is to be indicated; the effect of placing a resistance in parallel with another is to reduce the resistance between the two points touched; but the meter resistance is so high as to have but little effect.

READING HIGH VOLTAGES.

12. Two Voltmeters in Series. Voltages exceeding the rating of one meter may be indicated on two connected in series as in Fig. 11. Two voltmeters so connected cannot indicate a voltage equal to the sum of their ratings unless their resistances are proportional to their ratings. Thus, for two 500-volt meters to read 1,000 volts, their

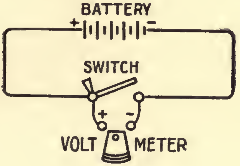

Fig. 10.

resistances must be equal so that each will get a p.d. of 500 volts, otherwise the needle of the lower-resistance meter will indicate less than maximum while that of the other will go off the scale. Similarly, 600-volt and 150-volt meters in series will

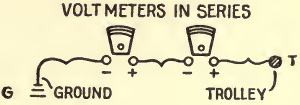

Fig. 11.

not read to 750 volts unless the resistance of the former is 4 times that of the latter. The maximum voltage readable on two meters of known resistance and rating, can be obtained by applying rule 5.

Rule 5. To determine the maximum voltage readable on two voltmeters of known resistance and rating in series, add the *meter resistances, multiply by the higher rating and divide by the higher resistance.*

Example 6. What is the maximum voltage readable on a 600-volt, 80,000-ohm voltmeter connected in series with a 500-volt, 60,000-ohm voltmeter?

Solution 6. From rule 5,

$$60{,}000 + 80{,}000 = 140{,}000$$
$$140{,}000 \times 600 = 84{,}000{,}000$$

and $84{,}000{,}000 \div 80{,}000 = 1{,}050$ volts. *Ans.*

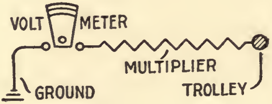

Fig. 12.

13. Voltmeter and Multiplier. The rating of a voltmeter can be increased by connecting a resistance in series as in Fig. 12. A resistance so used is called a *multiplier.* Multipliers are furnished on request but cannot, without extra calculation, be used with a meter other than the one for which adjustment was made. If in series with a meter is connected a resistance equal to its own, the applied voltage will divide equally between them; as the meter indicates but half the total voltage, the reading must be multiplied by 2; here 2 is the *constant* of the particular multiplier and voltmeter used. In any case, the constant of a voltmeter and multiplier can be gotten by applying rule 6.

Rule 6. To get the constant of a voltmeter and multiplier of known resistance, *add their resistances and divide by resistance of the voltmeter.*

Example 7. The range of a 500-volt, 60,000-ohm voltmeter is to be increased with a 49,000-ohm multiplier belonging to another voltmeter. What is the constant of the new arrangement?

Solution 7. From rule 6,

$$60{,}000 + 49{,}000 = 109{,}000$$

and $109{,}000 \div 60{,}000 = 1.817$. *Ans.*

Notes. Were the meter to indicate 500 volts the total potential difference would be $500 \times 1.817 = 909$ volts. An indication of 453 volts would mean a total e.m.f. of $453 \times 1.816 = 823$ volts, and so on.

The maximum rating of a voltmeter is indicated by the highest value marked on its scale. The resistance can be found on the certificate pasted on the inner side of the sliding box cover, or can be ascertained from the instrument maker by forwarding the meter number.

14. Determination of Multiplier. The series resistance required to increase a voltmeter range by a certain amount, can be gotten by rule 7.

Rule 7. To determine the multiplier resistance required to increase a voltmeter range by a certain amount, *divide the new range by the old, to get the* *constant; then multiply the meter resistance by the constant and subtract the meter resistance.*

Example 8. The maximum rating of a 500-volt, 60,000-ohm voltmeter is to be increased to 550 volts. What multiplier resistance must be used?

Solution 8. The new maximum being 550 and the old, 500 volts, the constant is $550 \div 500 = 1.1$:

$$60{,}000 \times 1.1 = 66{,}000$$

and $$66{,}000 - 60{,}000 = 6{,}000 \text{ ohms.} \quad \textit{Ans.}$$

15. Experimental Determination of the Voltmeter Constant. The constant of a voltmeter and multiplier of known or unknown resistance can be ex-

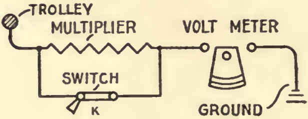

FIG. 13.

perimentally determined as follows: To a voltage less than the maximum rating of the meter, connect the meter, multiplier and switch *K*, as in Fig. 13. With *K* closed, the meter indicates line voltage; with *K* open, the multiplier is in series. The test consists in taking readings with *K* open, and closed, then applying rule 8.

Rule 8. To determine experimentally the constant of a voltmeter and multiplier from a deflection with the multiplier cut out and another with the multiplier cut in, *divide the first deflection by the second.*

Example 9. The deflection with the multiplier cut out, Fig. 13, is 450; with it cut in, 405; find the constant for that arrangement.

Solution 9. From rule 8,

$$450 \div 405 = 1.111, \text{ Constant. } \textit{Ans.}$$

Note. Twenty-eight 16-c-p. incandescent lamps in series would be about right ($28 \times 220 = 6{,}160$ ohms) for the multiplier of example 8. As it is not exact, however, the constant would be found by rule 8.

Example 10. The constant of a voltmeter with 28

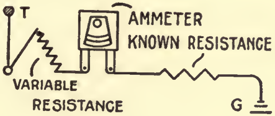

FIG. 14.

lamps in series, is 1.11. To what total voltage would a deflection of 500 correspond?

Solution 10. From the note, Art. 13,

$$500 \times 1.11 = 555 \text{ volts. } \textit{Ans.}$$

AMMETER RESISTANCE METHOD.

16. To get the p.d. in a conductor of known resistance, connect an ammeter in series, Fig. 14, establish a current, take a reading and apply rule 9.

Rule 9. To calculate the p.d. in a conductor of known resistance carrying direct current, *multiply the current by the resistance.*

Example 11. The resistance of two G. E. 800 field coils in series is 0.624 ohm. What voltage do they consume when the motor carries 60 amperes?

Solution **11.** From rule 9,

$$0.624 \times 60 = 37.44 \text{ volts. } \textit{Ans.}$$

Example 12. A G. E. 1,200 motor shunt-wound to run shop shafting has a field-circuit resistance of 330 ohms; one field coil is to be dried by current. On a line voltage of 500 and in series with a resistance of 200 ohms, to what p.d. will the field coil be subjected?

Solution 12. The G. E. 1,200 motor has two field coils connected in series, so the resistance per coil is 165 ohms. The field coil and outside resistance in series, then measure $165+200=365$ ohms. From rule 2, 500 volts will establish through 365 ohms, a current of $(500 \div 365)$ 1.3 amperes. From rule 9, then, the p.d. in the coil is

$$1.3 \times 165 = 213.5 \text{ volts. } \textit{Ans.}$$

Note. In operation 500 volts are applied to 2 coils in series, so each gets a p.d. of 250 volts; 213.5 volts is, then, perfectly safe.

REDUCING EFFECTIVE VOLTAGE.

17. The voltage on a device can be changed by regulating that of the supply, but this is impracticable except on a dynamo used exclusively for testing. The common method is to put resistance in series to consume part of the applied voltage, the remainder acting on the device in question. For testing, the voltage can be varied by using storage cells, the number in series being adjusted to suit the work; but storage cells are seldom available. A good way to get any voltage from 0 to full line-voltage is by the use of *proportion lines*. In Fig. 15, R is a resistance connected from trolley to ground through switch K; if R is composed of similar units such as cast iron resistance grids, it is easy to determine how many units must be included, to get a desired voltage. Supposing R to be a series of 200 G. E. grids, section 26510, 0.1 ohm each, the 200 grids will measure 20 ohms and the current on closing K will be $500 \div 20 = 25$

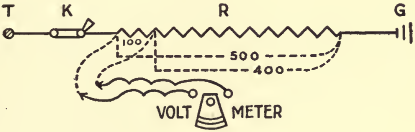

FIG. 15.

amperes. As there is a drop of 500 volts in 200 grids, the drop per grid is $500 \div 200 = 2.5$ volts. If the volt-lines, here called proportion lines, because they tap a certain proportion of the total voltage, be placed across 1 grid, the meter will indicate a drop of 2.5 volts and if the lines be placed across 10 grids, the drop indicated will be 25 volts. In any case if one proportion line is applied to trolley or ground and the other to an intermediate grid, the included voltage is the number of grids between them, times the drop per grid. If R is not composed of similar units, the desired proportion of the total voltage can be first found with the voltmeter, and the device to be energized then connected to the points so found. Proportion lines are especially useful in experimental work and in adjusting voltmeter multipliers by trial. Thus in Fig. 13 the line voltage might exceed the range of the meter, in which case closing K would injure the instrument; the proportion lines afford a safe voltage for making an adjustment that would hold for the higher voltages.

Lamp Method.

18. Voltage can be measured approximately by finding out how many similar incandescent lamps of known voltage and in series, it will light to full brilliancy; this found, the total voltage acting is that marked on each lamp base multiplied by the number of lamps in series; if the test voltage lights twenty 110-volt lamps, its value is $20 \times 110 = 2{,}200$ volts. Were the lamps 50-volt lamps, the voltage acting would be $20 \times 50 = 1{,}000$. The lamp method of indicating voltage is applicable to direct-current (d.c.) and alternating-current (a.c.) circuits. In a.c. insulation testing, lamps are used on the high tension side of the transformer to indicate the test voltage. Series of 5-volt or 10-volt lamps are useful where only d.c. instruments are available and a.c. voltages must be indicated; a voltage of 500 will light 50 ten-volt lamps to normal brilliancy and the voltage can be indicated within a narrow margin of error.

RESISTANCE MEASUREMENTS.

INTRODUCTION.

19. Resistance is the opposition that substances offer to the electric current through them. Insulators offer great resistance; conductors, comparatively little. A small conductor has more resistance than a large one of the same length and material; a long conductor, more than a short one of the same size and material. Considering two or more conductors, their combined resistance depends on how they are connected: if connected to increase

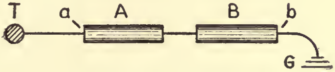

FIG. 16.

the cross section of the current path, their combined resistance will be less than that of one conductor; if connected to increase the length of the path, their combined resistance will be greater than the resistance of one conductor.

RESISTANCE IN SERIES.

20. Two or more conductors so connected that the current must pass through all in succession, are in *series*; in Fig. 16, conductors *A* and *B* are in series; the only path of the current is through each to reach the other and a break in either will stop the current. If A and B are each 1 ohm, the resistance from A to b is 2 ohms; hence rule 10.

Rule 10. To get the resistance of two or more conductors connected in series, *add their individual resistances.*

Example 13. On the first notch of a series parallel controller, the car wiring, controller contacts, starting coil and car motors are in series. If the starting coil measures 5.52 ohms, the wiring and contacts, 0.3 ohm and the two motors in series, 0.8 ohm, what is the resistance of the current path from trolley wheel to rail?

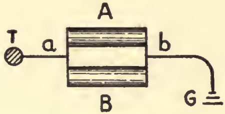

FIG. 17.

Solution 13. From rule 10,

$$5.52 + 0.3 + 0.8 = 6.62 \text{ ohms.} \quad \textit{Ans.}$$

Note. This shows that in calculating the resistance of the starting-coil for a car, other circuit resistances must be considered.

RESISTANCES IN PARALLEL.

21. Conductors so connected that a break in one does not stop the current in the others, are in *parallel* or *multiple.* In Fig. 17 conductors A and B are in parallel; current can traverse either after the other has been removed. As the resistance of a large conductor is less than that of a small one of the same length and material and as two conductors in parallel are equivalent to a single one of the same length and material and of their combined cross section, the resistance of two conductors in parallel is less than that of either alone. If *A* and *B* are each 1 ohm, the resistance from *a* to *b* is half an ohm.

22. Parallel Resistance of Equal Resistances. The parallel resistance of any number of equal resistances can be calculated from rule 11.

Rule 11. To get the resistance of two or more equal resistances in parallel, *divide the resistance of one of them by their number.*

Example 14. A 16-c-p., 110-volt incandescent lamp measures about 220 ohms. Calculate the resistance of 5 such lamps connected in parallel.

Solution 14. By rule 11,

$$220 \div 5 = 44 \text{ ohms. } \textit{Ans.}$$

Example 15. Five 110-volt, 32-c-p. incandescent lamps in series, measure about 550 ohms. What is the resistance of 7 such series in parallel?

Solution 15. By rule 11, (Fig. 18)

$$550 \div 7 = 78.57 \text{ ohms. } \textit{Ans.}$$

Note. Conductors so connected that some are in series and others are in parallel, are said to be in *parallel-series* or *multiple series.* In Fig. 18 the individual lamps in a row are in series—unscrewing a lamp will extinguish a row. The rows, however, are in parallel with each other; extinguishing one row will not stop the current in the others.

23. Parallel Resistance of Any Two Resistances. The parallel resistance of two equal or unequal resistances can be calculated by rule 12.

Rule 12. To get the parallel resistance of any two known resistances, *divide their product by their sum.*

Example 16. A 110-volt, 16-c-p. incandescent lamp measures 220 ohms; a 110-volt, 32-c-p. lamp, 110 ohms. What is their parallel resistance?

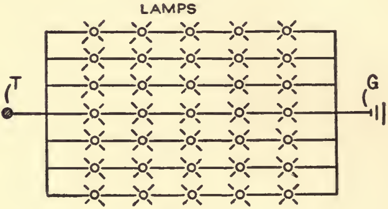

FIG. 18.

Solution 16. By rule 12,

$220 \times 110 = 24{,}200$; and $220 + 110 = 330$ and $24{,}200 \div 330 = 73.33$ ohms. *Ans.*

Example 17. A G. E. 1,000 field coil measures 0.44 ohm; a shunt for it, 1.1 ohms; what is their parallel resistance?

Solution 17. By rule 12,

$0.44 \times 1.1 = 0.484$ and $0.44 + 1.1 = 1.54$ and $0.484 \div 1.54 = 0.314$ ohm. *Ans.*

24. Parallel Resistance of Two or More Unequal Resistances. The customary method of calculating the parallel resistance of more than two unequal resistances, is complicated and hard to remember. Rule 13 is easy to retain.

Rule 13. To get the parallel resistance of more than two unequal resistances, *find the parallel resistance of any two of them by rule* 12; *then the parallel resistance of this result and a third resistance*; *then the parallel resistance of this and a fourth resistance and so on until all of the resistances have been so used.*

Example 18. Five conductors measuring 1, 2, 3, 4 and 5 ohms are connected in parallel. What is their parallel resistance?

Solution 18. The parallel resistance of the first two conductors $= (2 \times 1) \div (2+1) = 2 \div 3 = \frac{2}{3}$ ohm.

The parallel resistance of this result and the third conductor $= (\frac{2}{3} \times 3) \div (\frac{2}{3} + 3) = 6/3 \div 3\frac{2}{3} = 6/3 \div 11/3 = 6/3 \times 3/11 = 18/33 = 6/11$ ohm.

The parallel resistance of this result and the fourth conductor $= (6/11 \times 4) \div (6/11 + 4) = 24/11 \div 50/11 = 24/11 \times 11/50 = 264/550 = 12/25$ ohm.

The parallel resistance of this result and the fifth conductor $= (12/25 \times 5) \div (12/25 + 5) = 60/25 \div 137/25 = 60/25 \times 25/137 = 60/137 = 0.437$ ohm. *Ans.*

Example 19. Five conductors have individual resistances 6, 7, 8, 9 and 10 ohms. What is their parallel resistance?

Solution 19. The parallel resistance of first two conductors $= (6 \times 7) \div (6 + 7) = 42 \div 13 = 42/13 =$ 3.23 ohms.

The parallel resistance of this result and the third conductor $= (3.23 \times 8) \div (3.23 + 8) = 25.84 \div 11.23 = 2.30$ ohms.

The parallel resistance of this result and the conductor $4 = (2.3 \times 9) \div (2.3 + 9) = 20.7 \div 11.3 =$ 1.83 ohms.

The parallel resistance of this result and conductor $5 = (1.83 \times 10) \div (1.83 + 10) = 18.3 \div 11.83 =$ 1.54 ohms. *Ans.*

25. Calculation of Resistance to be Added to Give a Certain Parallel Resistance. It may be desired to know what resistance must be connected in parallel with an existing resistance to give a certain parallel resistance. (See rule 14).

Rule 14. To get the resistance to be connected in parallel with a known resistance to give a desired parallel resistance, *multiply the existing known and desired parallel resistances together and then divide by their difference.*

Example 20. An existing conductor measures 5 ohms; it is desired to connect in parallel with it a conductor of resistance such that the parallel resistance shall be 1.75 ohms. What must be the resistance of the added conductor?

Solution 20. Here the existing resistance is 5 ohms and the desired parallel resistance is 1.75 ohms. By rule 14, then,

$5 \times 1.75 = 8.75$ and $5 - 1.75 = 3.25$ and $8.75 \div 3.25 =$ 2.692 ohms. *Ans.*

26. Where an existing conductor is composed of several parallel conductors of known individual but unknown parallel resistance and another conductor is to be added to reduce the parallel resistance to a certain value, find the existing parallel resistance by rule 13; then considering this result as the existing resistance, apply rule 14. Hence rule 15.

Rule 15. To get the resistance of a conductor that is to be connected in parallel with existing parallel conductors to bring their final parallel resistance to a certain value, *find the existing parallel resistance by rule* 13 *and use it as the existing resistance in applying rule* 14.

Example 21. Two conductors measuring 3 and 7 ohms are in parallel and it is desired to connect in parallel with them, a third conductor of resistance such that the final parallel resistance of the three conductors shall be 1 ohm. What must the added conductor measure?

Solution 21. As one conductor measures 3 and the other 7 ohms, the existing parallel resistance is, by rule 13, $(3 \times 7) \div (3 + 7) = 21 \div 10 = 2.1$ ohms. Calling 2.1 ohms the existing resistance and applying rule 14, $2.1 \times 1 = 2.1$ and $2.1 - 1 = 1.1$ and $2.1 \div 1.1 = 1.9$ ohms. *Ans.*

Note. 1.9 ohms is the resistance of the conductor to be connected in parallel with the 3 and 7-ohm conductors to give a final parallel resistance of 1 ohm. To test the result, suppose that it is desired to find the parallel resistance of the 1.9, 3 and 7-ohm resistances; by rule 13 the parallel resistance of the first two conductors is $(1.9 \times 3) \div (1.9+3) = 5.7 \div 4.9 = 1.16$ ohms and the parallel resistance of this result and the third conductor is, $(1.16 \times 7) \div (1.16+7) = 8.42 \div 8.16 = 1.0$ ohm. *Ans.*

Example 22. The resistance of a starting coil for four 40-h.p. motors on a 20-ton car to operate on 550 volts, is to be 4 ohms maximum. The 4 ohms are represented by a single section in circuit on the first notch. On notch 2, a second section cut in parallel with the first, reduces the circuit resistance to 2 ohms; in the same manner, on the third notch the resistance is reduced to 1 ohm; on the fourth, to 0.5 ohm; on the fifth, to 0.3 ohm; on the sixth, to 0.1 ohm, and on the seventh notch a short-circuiting wire reduces the starting coil resistance to 0. It is thus seen that six resistance sections are needed and it is desired to know what must be the resistance of each that it may produce the stated change when it is introduced? The short-circuiting wire is not to be considered as a section.

Solution 22. *First notch.* In circuit here is one section of 4 ohms—*a*, Fig. 19.

Second notch. Here is cut in parallel, section *b*, such that the resistance of *a* and *b* in parallel shall be 2 ohms. The resistance existing is 4 ohms and the desired parallel resistance, 2 ohms, so, by rule 14, the resistance of added coil *b* is, $(4 \times 2) \div (4-2) = 8 \div 2 = 4$ ohms = resistance of coil or section *b*.

Third notch. The resistance existing on notch 2 is 2 ohms and the third notch must add a section *c*, such that the parallel resistance of *a*, *b* and *c*, shall be 1 ohm. The resistance of section *c* is, then, $(2\times1)\div(2-1) = 2\div1 = 2$ ohms = resistance of coil *c*.

Fourth notch. The existing resistance on notch 3 is 1 ohm and notch 4 must add a coil *d* such that the parallel resistance of *a*, *b*, *c* and *d* shall be 0.5 ohm. The resistance of section *d* must be, then,

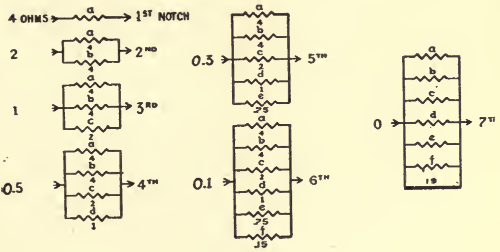

FIG. 19.

$(1\times0.5)\div(1-0.5) = 0.5\div0.5 = 1$ ohm = resistance of section *d*.

Fifth notch. The existing resistance on notch 4 is 0.5 ohm and the fifth notch is to add a coil *e* such that the parallel resistance of *a*, *b*, *c*, *d* and *e* shall be 0.3 ohm. The resistance of added coil, *e*, is, $(0.5\times0.3)\div(0.5-0.3) = 0.15\div0.2 = 0.75$ ohm = resistance coil *e*.

Sixth notch. The resistance existing on notch 5 is 0.3 ohm and the sixth notch is to add a section *f* such that the parallel resistance of *a*, *b*, *c*, *d*, *e* and *f* shall be 0.1 ohm. The resistance of *f* is, then, $(0.3\times0.1)\div(0.3-0.1) = 0.03\div0.2 \div 0.15$ ohm, resistance of *f*.

Seventh notch. As the starting coil is entirely short-circuited here, no resistance section is added, but instead, a heavy wire 19.

Note. The advantages of this parallel type of resistance coil over the better known series type, are that the current carrying capacity increases as the current does and an open circuit in a resistance connection affects operation only on the notch in which the open circuit is directly involved.

CONDUCTOR RESISTANCE.

Voltmeter Ammeter Method.

27. The usual shop method of measuring conductor resistance is with an ammeter in series with the conductor and a voltmeter across it. The circuit includes a variable resistance to regulate the current, unless the test resistance is known to be sufficient. The test is to pass a safe current through the circuit, take simultaneous voltmeter and ammeter readings, then apply rule 16.

Rule 16. To get the resistance of a conductor from simultaneous readings of a voltmeter in parallel and an ammeter in series with the conductor, *divide the voltmeter reading by the ammeter reading.*

Example 23. In Fig. 20, *x* is the starting coil for a 20-ton car operated by four 40-hp. motors and a series-parallel controller; describe how its resistance may be measured with a voltmeter and ammeter.

Solution 23. In the test from which the example was taken the voltmeter indicated 120 volts and

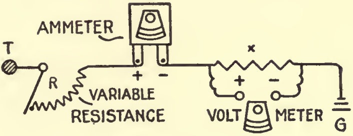

FIG. 20.

the ammeter, 30 amperes; by rule 16, then, the resistance was,

$$120 \div 30 = 4 \text{ ohms.} \quad \textit{Ans.}$$

Example 24. The resistance of the top and bottom sections of a set of electric heaters is to be

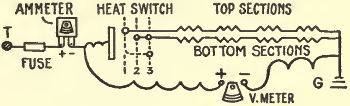

FIG. 21.

measured with a voltmeter and ammeter. How can this be done?

Solution 24. Fig. 21 shows car heater connections; on notch 1 of the switch, the top sections in series are active; on notch 2, the bottom sections are in series. The ammeter is in series with the heater trolley tap and the voltmeter is across trolley and ground. In this test the current reading on notch 1 was 6 amperes and the voltage, 486. On notch 2 the current was 10 and the voltage, 490.

(*a*) Resistance top sections = $486 \div 6 = 81$ ohms. *Ans.* (*a*).

(*b*) Resistance bottom sections = $490 \div 10 = 49$ ohms. *Ans.* (*b*).

Note. On notch 3 the top sections in series and

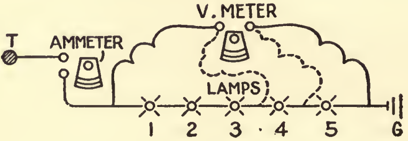

FIG. 22.

the bottom sections in series are in parallel with each other. The parallel resistance of the two sections is, by rule 12, $(81 \times 49) \div (81 + 49) = 3969 \div 130 = 30.5$ ohms. Also, by rule 2, the current on a 500 volt circuit would be, $500 \div 30.5 = 16.4$ amperes, showing that the current taken to heat an electric car is very considerable.

Example 25. Wanted, to measure with ammeter and volt-meter, the resistance per lamp and total resistance of a lamp circuit of five 16-c-p., 110-volt incandescent lamps connected in series.

Solution 25. Connect the lamp circuit and a low reading ammeter in series as in Fig. 22. With the volt-meter take the drop in the whole lamp circuit, as indicated by the full line, then the drop in each lamp, as indicated with the dotted lines to lamp 4. In each case take the corresponding ammeter reading and tabulate the results as shown.

Note. The measured resistance of the circuit is less than the sum of the measured resistances of the individual lamps, because voltage variations prevented strictly simultaneous readings; and because the ammeter (25 amperes) permitted excessive error in reading currents so small as 0.5 ampere. Decided difference in the brilliancies of lamps 4 and 5 foretold the decided difference in their resistances.

	Volts		Amperes		Ohms
All,	505	÷	0.50	=	1,010.0
1,	101	÷	0.49	=	206.1
2,	99	÷	0.48	=	206.2
3,	103	÷	0.50	=	206.0
4,	102	÷	0.49	=	208.1
5,	100	÷	0.52	=	192.3

VOLTMETER—RESISTANCE METHOD.

28. When voltage is applied to resistances connected in series the greatest p.d. is found in the greatest resistance, the least in the least resistance and so on, the voltage distributing itself according to the distribution of resistance. On this fact is based rule 17.

Rule 17. To measure an unknown resistance with a volt-meter and known resistance, establish a current through the known and unknown resistances in series and read the drop on each at the same current value; *multiply the known resistance by the drop in the unknown and divide by the drop in the known.*

Example 26. The resistance of a field coil is to be measured with a volt-meter and a similar field coil that is sound. How can it be done?

Solution 26. Connect a switch K, a variable

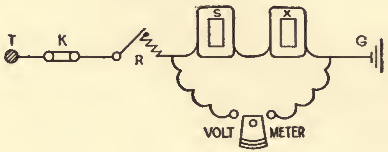

FIG. 23.

resistance R, a standard coil S, and test coil X in series, as in Fig. 23, and use a safe value of current. Take the drop in the standard coil, then in the test coil, then in the standard coil again, to see that the current has not varied, then apply rule 17. In one case the standard measured 0.08 ohm and its drop was 3.5 volts; the test coil gave 2 volts drop:—

$0.08 \times 2 = 0.16$ and $0.16 \div 3.5 = 0.0457$ ohm. *Ans.*

Example 27. A set of field coils is to be measured in an installed car motor. How can the test be made with a volt-meter and a known resistance?

Solution 27. Connect the motor field coils, a switch, a variable resistance and a standard coil in series; use a safe value of current, take the drops on the standard and motor coils. If the motor has four coils, their drop should be four times that in the standard; if the motor field drop is more or less than it should be, all coils being at the same temperature, the faulty coil must be located by taking the drop on each. In one test the motor field drop was 10 volts and that in the 0.08 ohm standard, 3 volts. By rule 17, then, the resistance of the motor fields was, $(0.08 \times 10) \div 3 = 0.8/3 = 0.266$ ohm. *Ans.*

Note. The average resistance per coil $(0.266 \div 4 = 0.066)$ being too low, the motor was opened and the drop on each coil taken and compared with that on the standard at the same current. The drops on the standard and on each of three of the motor coils was the same, but on the fourth coil it was only 1 volt. As this was entirely too low, the insulation was ripped off and inspection showed the coil to be wound with too large a wire.

Note. In testing field coils, it is not customary to work out resistances, as comparison of drops suffices.

Example 28. With a low reading volt-meter, the resistance on the last series position of a controller is to be measured. How can it be done?

Solution 28. The only resistance available as a standard was a reel of 527 feet of No. 6 B & S copper wire, a wire table giving its resistance as 0.4 ohm per 1,000 ft. or 0.0004 ohm per ft. The standard resistance was, then, $527 \times 0.0004 = 0.21$ ohm. A switch, the standard and a variable resistance (not shown) were connected in series with the trolley pole as in Fig. 24. A controller was put on the last series notch, the brake set to prevent motion, current applied and drops read from the trolley wire to the trolley wheel and from the trolley wheel to the rail. In one test the drop on the car

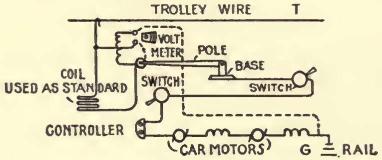

Fig. 24.

circuit was 60 volts and that, on the standard, 6 volts. The car circuit resistance was, then, by rule 17,

$$(0.21 \times 60) \div 6 = 2.10 \text{ ohms.} \quad \textit{Ans.}$$

Note. Overhauling the controller, cleaning the commutators and fitting new brushes reduced the resistance to 1.75 ohms. The measurement included the resistance of the 2 motors in series; to get the wiring and controller contacts separately, disconnect the motor terminals and connect corresponding cable terminals.

AMMETER-RESISTANCE METHOD.

29. Where great accuracy is not required and the voltage is fairly constant and the resistance to be measured is practically the total resistance of the circuit, it can be measured with an ammeter and known resistance. Connections are as in Fig. 25, where K' is a switch for short-circuiting the test resistance. Readings are taken with X in circuit, then with X out of circuit. The resistance value of X is then calculated by rule 18.

Rule 18. To measure an unknown resistance with an ammeter and a known resistance, connect

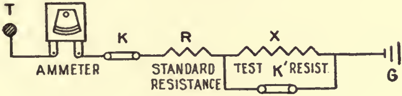

FIG. 25.

the meter and resistances in series, a switch being placed in parallel with the unknown. Use a safe value of current and take readings with K' opened and closed. *Divide the difference of the readings by the reading with K' open and multiply by the known resistance.*

Example 29. In Fig. 25, R is a 5-ohm starting coil; X, a starting coil for a 10-ton car equipped with two 40-hp. motors; K, a main switch and K', a switch for cutting X in and out of circuit. Wanted, resistance X.

Solution 29. On closing K and K', the current is 100 amperes; opening K' reduces the current to 45.5 amperes. By rule 18, then $100 - 45.5 = 54.5$ and $54.5 \div 45.5 = 1.19$ and $1.19 \times 5 = 6$ ohms. *Ans.*

DIFFERENTIAL VOLTMETER METHOD.

30. Taking simultaneously voltmeter and ammeter readings on a railway circuit is tedious, owing to voltage fluctuations. In measuring resistance with a voltmeter and known resistance (Art. 28), accuracy depends on getting both voltage readings

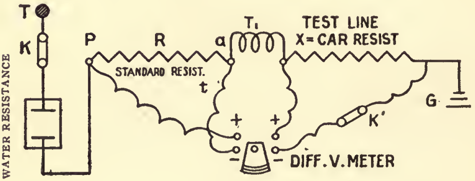

FIG. 26.

with the same current. A *differential voltmeter* has two coils connected in opposition; equal voltages applied to them, hold the needle at a central 0. The meter is used as follows: In Fig. 26 the meter has two pairs of terminals provided with test lines, one pair is connected to the test resistance and the other is so connected to a standard that one test point can be moved along the resistance metal. Current is established and the free test point moved along the standard until the needle is at 0. Under this condition the test and standard resistances are equal because the current in them and the p.d. across them is the same.

31. In an outfit for testing starting coils in position, the voltmeter is a Weston differential instrument reading to 50 volts on either side of 0. The standard resistance is a series of 220 G. E. grids, Sec. 26,510, measuring 22 ohms or 0.1 ohm per grid. With a water resistance the current is kept at a value such that the drop in the highest resistance likely to be measured will not exceed 50 volts. A car resistance, in position, is measured as follows: Switch K, water resistance, standard R and a long test cable $T1$ are in series. A hook on the far end of the test cable engages the trolley wheel which is lowered from the wire. Test resistance volt-lines, including switch K', normally open, connect to one pair of meter posts and the volt-lines from the standard connect to the other pair. The car brake is set to prevent starting, the car switch or circuit breaker closed and one controller put on the first notch. Switch K is closed and the current adjusted until the meter deflection does not exceed 50 volts when the standard volt-lines are at opposite ends of the standard resistance; on closing K' the deflection will decrease owing to the action of the voltmeter coil energized by the p.d. in the car starting coil. Free test point t is then moved toward P until the deflection becomes 0. Under this condition, the resistances of X and R will be equal and will be 0.1 ohm $\times$ number of grids from t to P. By placing under the standard a scale on which is marked the resistance corresponding to each grid from *a* to *P*, the device becomes direct reading.

Example 30. In measuring the resistance of a starting coil on a 21-ton car equipped with four 40-hp. motors, the 0 deflection obtains with *t* on the negative end of grid No. 30. The coil measures what?

Solution 30. By instructions of Art. 30,

$$30 \times 0.1 = 3.00 \text{ ohms.} \quad \textit{Ans.}$$

Note. The object of having the total standard resistance greater than that of any starting coil likely to be measured, is to reduce the test current to a value that will not cause excessive heating.

Wheatstone Bridge Method.

32. The principle of all Wheatstone bridges can be understood in conjunction with Fig. 27, where battery *B* maintains a current through the branched circuit *a-P-b*, *a-Q-b*. The path of the current is from *a* to *b* through two paths, *a-M-X-b*, and *a-N-R-b*. As the p.d. from *a* to *b* is fixed, the drop through one path is the same as that through the other and for every point in one, there is a point in the other at the same potential. If one end of a galvanometer is fixed to junction *M X*, as in the diagram, and the other end to junction *N R*, there will be no deflection on closing *K*, if points *p* and *q* are at the same potential. Since the p.d. distributes itself according to the distribution of resistance, even if *p* and *q* are not at the same potential they can be made so by varying the resistance of one of the arms, say *R*, or of two arms at once as would be the case were one end of the galvanometer moved along *N-R*. In commercial bridges of the *plug* type, *R*, called the *rheostat arm*, is a resistance that can be varied by inserting or withdrawing metal plugs from taper sockets. In *slide-wire* bridges, arms *N* and *R* are continuous in the form of an exposed wire along which one end of a galvanometer or telephone circuit can be

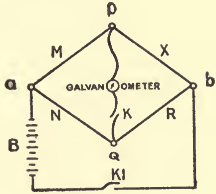

FIG. 27.

moved. As plug bridges are less adapted to shop use than slide-wire bridges, only the latter will be considered here.

HOMEMADE SLIDE-WIRE BRIDGE.

33. Fig. 28 shows a slide-wire bridge easily made at small cost and with which good work can be done. On a seasoned, hard wood board *a'*, 42 in. by 6 in. by 1 in., are mounted castings *b'* provided with connecting posts *c'*. A small uniform german silver wire *d* is stretched between the end fittings and under it is a paper scale 1 meter (39.37 in.) long, divided into 1,000 equal divisions. The battery, including a key K', is connected to junctions $M\ N$ and $R\ X$, as in Fig. 27; one end of the galvanometer circuit is connected to junction $M\ X$ and the other to junction $N\ R$. Contact Q, free to be slid along wire N-R is the dividing point between arms N and R. Any movement of Q changes the relative resistances of these two arms. As wire N-R is of uniform cross section the resistances of arms N and R need not be known;

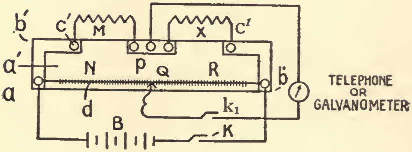

FIG. 28.

but the number of divisions in each must be known when taking a reading. M is a known resistance and X, the resistance to be measured. Having the connections made, a measurement consists in closing key K and sliding Q along the wire until the galvanometer shows no deflection. Where a telephone is used, Q is tapped along the wire until a point is reached where the tapping causes no click in the telephone. The nearer equal resistances M and X are, the more accurate the result. When the *balance point* is located, the bridge is said to be *balanced* and the resistance of X in ohms can be calculated by rule 19.

Rule 19. To get the unknown resistance corresponding to a balance on a slide-wire bridge connected as in Fig. 28, *multiply standard resistance M by the number of divisions in the diagonally opposite wire arm and divide by the number of divisions in the adjacent wire arm.*

Example 31. In measuring the resistance of an arc headlight rheostat a balance is obtained when contact Q rests on division 615. To what X resistance does this correspond when the value of M is 100?

Solution 31. Here the standard resistance is 100 ohms; diagonally opposite arm R has 615 divisions and adjacent arm N, 385 divisions. By rule 19, rheostat resistance $= 100 \times 615/385 = 159.7$ ohms. *Ans.*

Example 32. A standard 1-ohm coil is used at M to measure 4 G. E. 1,000 field coils connected in series, a balance obtaining with contact Q on division 320. Wanted the resistance of the four new field coils.

Solution 32. Here the standard resistance is 1 ohm, the opposite arm R has 320 divisions and the adjacent arm N, 680 divisions. By rule 19, then, the resistance of the motor field coils is,

$$1 \times 320/680 = 0.47 \text{ ohm.} \quad \textit{Ans.}$$

Note. Where a telephone is used there will be times when the point of silence cannot be exactly decided, owing to the click ceasing on a considerable stretch of the wire. For example, it may cease at division 590 when moving Q from the 0 end of the wire, and at 600 when moving Q from the 1,000 end; in such cases find the points at which the click ceases in both directions and take the point of balance as half way between them. In the case just supposed the balance point would be taken as division 595.

OHMMETER.

34. An **ohmmeter** is a slide-wire bridge on the scale of which the balance-value of the graduations is marked. In measuring, it is only necessary to get a balance and read the number opposite the balance point as the value of the unknown resistance. The ohmmeter is *direct reading* as opposed to regular bridges in which calculation is required. All bridges are ohmmeters in that they measure ohms but the name ohmmeter is confined to those bridges in which the value of X can be read off the scale on getting the balance. If, Fig. 28, with a certain standard resistance at M, different known resistances be successively inserted at X, the balance point found and marked with the balancing value of X, the bridge becomes direct reading on all points so marked. By thus calibrating 20 or 30 divisions, then equally dividing intermediate portions of the scale, the whole scale becomes calibrated and the slide-wire bridge becomes a fairly accurate ohmmeter, for all resistances that do not bring the balance point near the ends of the scale. Having calibrated the bridge for $M=1$ ohm, say, if M be made 10 ohms, the resistance value of each scale division is increased 10 times. To illustrate: If M and X are both 1 ohm the balance point on the scale will be at its center or 500 mark, which, accordingly can be marked 1 ohm. If M and X are made 10 ohms, the balance point will remain at 500, but to get the real X value to which the balance is due, the one ohm marked there must be multiplied by 10 or a second row of numbers

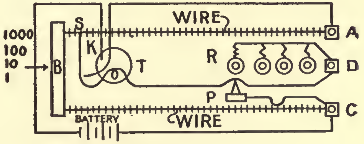

Fig. 29.

inscribed. A third row corresponding to an M value of 100 ohms and a fourth row for $M=1{,}000$ ohms can be inscribed and the useful range thereby enlarged.

35. Fig. 29 is a top view of an ohmmeter, Fig. 30 showing the corresponding bridge connections. A, D and C are connecting posts and A-B-C, the slide-wire including brass end piece B which unites the two sections of wire. At R are 4 resistance coils with sockets to be engaged by plug P. Over the divisions are four rows of numbers inked in black, red, blue and brown. In testing, if P plugs a hole marked black, red, blue or brown, then, on getting a balance by tapping pointer S along the wire, the resistance of X can be read directly from the numbers of the same color. T is a telephone receiver provided with a key K which must be closed before seeking the balance point by tapping pointer S on the wire. Key K is the battery switch and the intermittent contact of

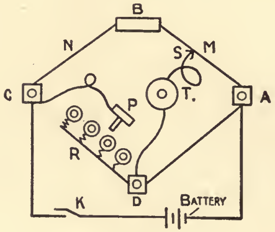

FIG. 30.

pointer S corresponds to switch $K1$ of Fig. 28. On all bridges the battery key must be closed first to allow the testing current to become steady; otherwise, when testing field coils and other resistances having what is called *self inductance*, correct results cannot be obtained.

36. Measurements with the ohmmeter are made as follows: Connect the unknown resistance to A and D; plug P into one of the four holes; take pointer S in one hand and with the other hold the 'phone to the ear; close K and tap S along the wire until the point of *silence* or least noise is found; the value of X can then be read on the numbers of the color indicated by the position of plug P. Assuming X to be such that the balance point lies on bar B, the X value to be read depends on the position of P; the black hole has the lowest value and in the order black-red-blue-brown, each color has 10 times the value of the color preceding. A balance at B with the black hole would give an X value of 1 ohm; red hole, 10 ohms; blue hole, 100 ohms; brown hole, 1,000 ohms. When measuring, select, by trial, the color that brings the balance point near the centre of the scale, where the divisions are farther apart and more easily read. In cases where the point of silence cannot be exactly located, follow the instructions given in the note of Art. 33. Where there is an approximate idea as to the value of X, select M to be as nearly equal as practicable, as the balance point will then fall near the scale center and results will be more accurate. The lower the color used at R, the lower the unknown resistance practicable to be measured at X and the higher the color at R, the higher the resistance that can be accurately measured at X.

Example 33. In measuring 4 G. E. field coils in the motor, the telephone ceases to click at division 450 and begins at division 470. To what division would the point of silence correspond?

Solution 33. As the stretch of silence extends from division 450 to division 470, the silence point may be taken half way between division 460, giving the resistance as 0.46 ohm.

INSULATION RESISTANCE.

Introduction.

37. Insulation can be tested with a bridge, bell circuit, magneto, lamp circuit, voltmeter or a.c. transformer. The first three devices are objectionable, in that the voltage used is too low to accurately indicate the condition of the insulation under test; they are better suited to prove connection between parts that should be connected: especially is the bell circuit adapted to such work as "ringing out" car connections. Insulation testing voltage should be sufficient to send a signal current through existing defects and to break down weak spots likely to break down later. A bridge or bell circuit will indicate perfect insulation between two commutator bars that almost touch, because the resistance of the thinnest layer of air or other insulation, so far as low voltage will indicate, is perfect. Any test using 500 volts or more would indicate the insulation to be below standard and would probably break down the weak point and indicate it as a short-circuit.

High voltage subjects insulation to stresses that weak spots cannot stand; but if too high and injudiciously applied, insulation formerly perfect for the work in hand may be injured. Even 500-volt lamp circuit tests can do harm if the contacts between which the test is made are close together, because the high voltage breaks down the insulation and starts an arc that carbonizes surrounding surfaces. Car equipment insulation should stand at least 2000 volts—the pressure at which the lightning arresters act. If other insulation will allow lightning to pass more readily than does the arrester path, the arrester will not give the intended protection.

Voltmeter Method.

38. The measurement of insulation with a voltmeter depends on the fact that voltage applied to

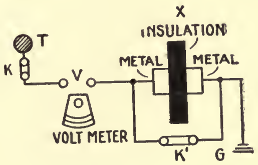

Fig. 31.

a circuit distributes itself according to the distribution of the circuit resistance. In Fig. 31, T is the trolley wire; V, a high-resistance voltmeter, and X, a sample of insulation held between two metal plates that do not touch each other. On closing K, sufficiently good insulation will prevent any deflection of the meter, because the insulation resistance is so high compared to that of the meter, that the entire line drop is across the insulation. This does not mean perfect insulation, for a higher voltage or more sensitive meter would show it to be imperfect. If the insulation resistance is low enough to permit an appreciable current, there will result a deflection indicating the drop taking place through the voltmeter resistance. The insulation here acts as a multiplier of unknown resistance, the value of which is to be determined experimentally (see Art. 12).

39. The line voltage being constant, if part of it drops through the meter, the remainder must drop through the insulation, so that the difference between the line voltage and meter reading, is the *insulation drop*. The voltmeter and insulation drops will have the same relation as the voltmeter and insulation resistances that cause them. Having the two drops and the voltmeter resistance, the insulation can be calculated by rule 20.

Rule 20. To measure insulation with a voltmeter, connect the meter and insulation in series across the line. *Subtract the meter deflection from the line voltage to get the insulation drop; then multiply the meter resistance by the insulation drop and divide by the voltmeter drop.*

Example 34. With line voltage at 600, the p.d. in an 80,000-ohm voltmeter in series with the test insulation, is 500. Wanted, the insulation resistance.

Solution 34. As line voltage is 600 and meter reading 500, the insulation drop is $600 - 500 = 100$ volts. By rule 20, then, the insulation resistance is

$(80,000 \times 100) \div 500 = 8,000,000 \div 500 = 16,000$ ohms. *Ans.*

40. The usual rule, given as rule 21, uses the insulation drop indirectly.

Rule 21. To measure insulation resistance with a voltmeter, connect the meter and insulation in series across the line, the insulation having a switch K' in parallel to cut it in and out. Take a reading with the insulation cut out and another with it cut in. *Divide the reading with the insulation cut out, by that with the insulation cut in*; *then subtract* 1 *and multiply by the voltmeter resistance.*

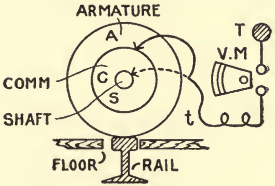

Fig. 32.

Example 35. With an 80,000-ohm voltmeter, the reading with the insulation cut out is 600 and with it cut in, 500. Wanted the insulation resistance.

Solution 35. By rule 21, $600 \div 500 = 1.2$ and $1.2 - 1 = 0.2$ and $0.2 \times 80{,}000 = 16{,}000$ ohms = resistance of the insulation. *Ans.*

41. The method of making the test on a ground-return system is indicated in Fig. 32, where armature insulation from commutator to shaft is to be tested. One voltmeter line connects to trolley and the other, t, is free. If the armature rests on the rail or other grounded part, the test is made as follows: touch t to the shaft; as the shaft is grounded, the needle will indicate full line voltage, showing the test circuit to be in order. If the armature does not touch a grounded part, the shaft or core must be grounded by a second line t', as in Fig. 33. In either case the next step is to touch line t to the commutator; the only path for test current to reach the ground is through

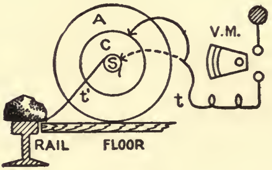

FIG. 33.

the insulation between the copper and iron parts of the armature and will cause a deflection indicating the insulation value.

Example 36. The insulation from winding to shaft is to be measured on an armature resting on the shop floor. The voltmeter is connected as in Fig. 32, the armature having been rolled on to the track rail. On touching t to the shaft, the reading is 500; on touching it to the commutator it is 30. What is the armature insulation resistance?

Solution 36. Here the voltmeter resistance is 80,000 ohms. The reading with the insulation cut out is 500 and with the insulation cut in it is 30. By rule 21, then, the insulation resistance is: $500 \div 30 = 16.66$ and $16.66 - 1 = 15.66$ and $15.66 \times 80{,}000 = 1{,}253{,}000$ ohms. *Ans.*

Note. As the insulation measures over 1,000,000 ohms (called 1 megohm), which is the usual standard of insulation, it is passed.

Example 37. Armature insulation is to be measured in a motor installed on a car. How can it be done with a 75,000-ohm voltmeter?

Solution 37. Disconnect the armature by drawing its brushes. With the voltmeter connected as in Fig. 32 or 33, touch *t* to the motor frame, then to the commutator. Assuming the first deflection to be 600 and the second 400 and applying rule 21, $600 \div 400 = 1.5$ and $1.5 - 1 = 0.5$ and $0.5 \times 75{,}000 = 37{,}500$ ohms. *Ans.*

Note. On cleaning the motor with an air blast and scraping and wiping the end of the commutator, the insulation deflection was reduced to 40, corresponding to an insulation resistance of more than a megohm and showing the former low insulation resistance to have been due almost entirely to accumulated oil, carbon, dust and dirt.

Example 38. A passenger entering a car, got a shock by rubbing against the rear end controller. How can the insulation from the controller frame to the ground be measured with a 60,000-ohm, 500-volt voltmeter?

Solution 38. Connect the voltmeter as in Fig. 32 or 33. Assume that touching *t* to the car truck causes a deflection of 490, but contact with the controller frame causes a deflection of only 45 volts. From rule 21, $490 \div 45 = 10.9$ and $10.9 - 1 = 9.9$ and $60{,}000 \times 9.9 = 594{,}000$ ohms, resistance of insulation. *Ans.*

Note. Controller frames are supposed to be well grounded so that an internal insulation defect will immediately cause a demonstration indicative of that fact. With a defective ground connection defective insulation within can charge the frame which can then shock anyone touching it and a grounded part simultaneously. With the frame well grounded, touching *t* to it will cause full line deflection. The preceding test, then, indicates a defective frame ground connection which should be immediately repaired.

42. The main precaution to be observed in locating weak insulation with a voltmeter, or its equivalent, is to disconnect the parts liable to defect and test them separately. Such a test will often show that no one part has a very low insulation resistance, but when the parts are connected as in operation, thereby paralleling the leakage paths, the total insulation resistance may be comparatively low. To illustrate: If a voltmeter on 600 volts be used to measure the insulation of each unconnected coil on a newly wound armature, no single coil thus tested may give an appreciable deflection; but if the coil leads be twisted together, thereby paralleling the leakage paths, the deflection may become from 10 to 50 volts.

Example 39. Some commutators that have been taken from defective armatures, are to be tested for insulation from bar to bar and from bars to shell. With connections of Figs. 32-35, how can this be done?

Solution 39. Hold one test line on the shell and successively touch every bar; then touch the test lines to adjacent bars, doing this for every pair of adjacent bars; in every case note the voltmeter

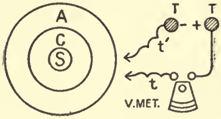

Fig. 34.

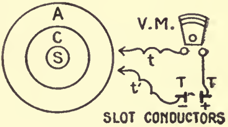

Fig. 35.

deflection. In one case using a 600-volt, 80,000-ohm voltmeter, the test was made as follows: Line *t'* was held to the shell and *t* touched to each bar to see that none was actually grounded to the shell; a piece of small copper wire was then twisted around the commutator, to connect all bars and their collective insulation to shell tested, with the bars connected together the deflection was 400 volts. The wire was then removed and the bar to bar insulation tested; in every case the bar to bar insulation deflection was full line voltage of 550, showing the insulation between bars to be 0.

By thoroughly cleaning the commutator ends, the deflection from bars to shell was reduced from 400 to 40, but the deflection from bar to bar remained 550. On taking a 3/32 inch cut off the commutator, the bar to bar deflection was reduced to 60 volts. Baking the commutator for 20 hours at 200 degrees F. reduced the bar to bar reading to 4 and the bar to shell, to 15 volts. By rule 21 the deflection of 15 corresponds to an insulation resistance of 2,852,800 ohms and the deflection of 4, to 10 megohms.

Notes. Grease and paraffin had soaked into the

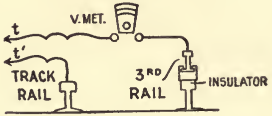

FIG. 36.

mica bodies and heat due to sparking had carbonized them, thereby short-circuiting the commutator from bar to bar—the lathe cut removed the carbonized areas. The commutator ends were filled with a greasy film of copper and carbon dust that bridged the insulation from bars to shell; cleaning removed this. The final baking improved the insulation deflections by expelling the accumulated moisture.

Figs. 34, 35 and 36 show the voltmeter connections, respectively, on a double overhead trolley system, slotted conduit system and third rail system. In testing from a slotted conduit system it is best that the devices under test make no contact with the ground. When this is unavoidable, as when testing an armature in a motor, care must be taken when connecting test line t', Fig. 35, for if one of the conductor rails is grounded and ground line t' is run to the conductor rail that is not grounded, see Fig. 37, the result is to ground both rails, thereby causing a short-circuit likely to burn

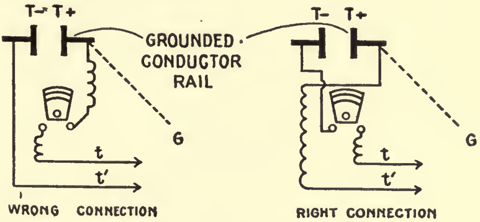

FIG. 37.

the tester. Where two test lines are used and one conductor rail is grounded, run the ground test line to the grounded rail. With one conductor rail grounded, however, but one test line is needed, as the connections of Fig. 32 can be used.

43. In voltmeter insulation tests it is the rule to see rather that the insulation reading does not exceed a specified value, than to find the actual insulation resistance. For example, if the management decides that all insulation must exceed half a megohm, 500,000 ohms, it is then necessary to know what voltmeter deflection corresponds to this insulation value.

Rule 22. To find the deflection corresponding to a specified insulation resistance, with a voltmeter of known resistance, on a line of known voltage, divide the product of the line voltage and the voltmeter resistance by the sum of the voltmeter resistance and the specified insulation resistance.

Example 40. On a 650-volt, 80,000-ohm voltmeter, what deflection corresponds to an insulation resistance of 0.5 megohm, the line voltage being 601?

Solution 40. By rule 22, $601 \times 80{,}000 = 48{,}080{,}000$, and $500{,}000 + 80{,}000 = 580{,}000$. $48{,}080{,}000 \div 580{,}000 = 83$ deflection. *Ans.*

Example 41. To what deflection would a resistance of 1 megohm correspond?

Solution 41. By rule 22, $601 \times 80{,}000 = 48{,}080{,}000$ and $1{,}000{,}000 + 80{,}000 = 1{,}080{,}000$. $48{,}080{,}000 \div 1{,}080{,}000 = 46+$ deflection. *Ans.*

Lamp Circuit Method.

44. The common shop and road method for testing insulation is with a lamp circuit. Fig. 38 shows connections for ground return and Fig. 39, for metallic return systems. The number of lamps to be connected in series depends on the voltages of the line and lamps and is gotten by dividing the line voltage by the voltage marked on the lamp bases, all lamps being the same. The lamps make the test no less severe, for so long as there is no current, the voltage tending to puncture the insulation, is the total line voltage, the lamp resistances being negligible compared to that of good insulation; and if the insulation fails, the lamps prevent violent demonstrations. The tests are made the same as the voltmeter tests; if the lamps light up, the insulation is poor or zero, according to the brilliancy of the lamp.

FIG. 38.

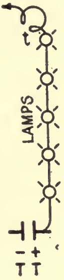

FIG. 39.

Insulation that is below standard may be too good to admit sufficient current to give any lamp indication; if on tapping the test point, a little arcing is observed, the insulation is not what it should be. In practice the correct number of lamps in series are mounted on a paddle and provided with test lines, as in Fig. 40, and a cleat provided on which to wind them when not in use.

45. When the source of voltage is a ground return system and neither of the contacts between which insulation is to be tested touches ground, a ground test line, t', Fig. 33, must be run, otherwise the test circuit will not be complete. Where one contact is grounded, but one test line, t, is required, but sometimes two are provided to cover all conditions. When using the test lines, one of which is grounded, to test insulation between contacts, one of which is grounded, the trolley test line, t, must be applied to the ungrounded contact and grounded test line, t', to the grounded contact. Without this precaution, the tester is liable to touch the trolley

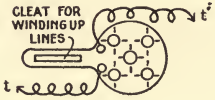

FIG. 40.

test-line to a grounded part and get an indication of short-circuit when none exists. Thus in Fig. 33 the armature does not touch the rail, but should such a contact be made unbeknown to the tester, if, in applying the test-lines, he happened to touch t to the shaft, the lamps would light independently of the existence of t', although the tester might not know it.

46. The lamp test is sometimes used to test the insulation from bar to bar on a commutator just machined, the current being sufficient to burn out short-circuits due to filings, chips and burrs;

the test may do more harm than good, for burning out a " short " starts an arc that may char surrounding insulation and make it worse than before the test. On this account it is well to use low voltage and apply it intermittently by tapping the test point on the bar to make and break contact. For burning out commutator shorts, a.c. voltage is better as it tends less to hold an arc.

Bell Circuit Method.

47. The low voltage of a bell circuit is of little use in testing the condition of insulation between

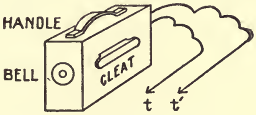

Fig. 41.

conductors that should not touch. Such tests will indicate an actual short-circuit, but they are more used to test the continuity of conductors and to identify the ends of concealed wires, such as car wires. A bell circuit usually consists of a wooden box with a handle and cleats for coiling the test lines when not in use (see Fig. 41). In the box are four dry cells in series and on top is an electric bell. The battery, bell and test lines are connected in series, so that touching the test points together closes the circuit, thereby ringing the bell. In testing, hold the points together before and after each test to see, by the ringing of the bell, that the circuit is in order. In applying the test points to opposite ends of the same conductor, the bell will ring if the conductor is continuous. Bell circuits are not adapted to test for open circuits in high-resistance conductors, such as fine wire magnet coils, the current being insufficient to ring the bell even when no break exists.

Magneto Method.

48. A magneto, such as that used for calling on a telephone, is an a.c. dynamo; turning the crank rotates an armature in a field produced by permanent magnets. Two test lines, t, t', connect to binding posts that represent the armature terminals. As with the bell test, the test-lines are touched before and after each test to insure continuity, and tests are made similarly, the test points being applied to the contacts between which the test for insulation or continuity is to be made. A magneto belted to shop shafting can be made to give from 200 to 300 volts, in which case it will give good results in testing insulation. At times (just frequent enough to be puzzling) a magneto will give misleading indications, because its current is alternating and the contacts between which insulation is being tested, may have great capacity like a condenser: the bell will vibrate although the insulation may be practically perfect. The effect can best be seen by holding the test points to the terminals of a condenser and turning the crank. If the condenser capacity is sufficient the bell will ring owing to the charging and discharging current that is produced with each alternation. Some car wiring systems and large generator armatures are able to produce this misleading effect.

HIGH VOLTAGE INSULATION TEST.

49. Such tests are usually a.c. at voltages of 1,000 or more. The manufacturing companies provide suitable apparatus for this work, but a homemade outfit can be made at small cost. Fig. 42 illustrates diagrammatically a high-tension outfit that did good service for years. *A* is an old two-pole railway motor connected to the line through switch *K*. On the pinion end of the armature are two insulated metal rings; one taps

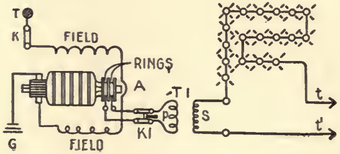

Fig. 42.

to the back end of the conductor connecting to any commutator bar and the other to the back end of the conductor connecting to the opposite bar. On closing *K* the motor runs as a d.c. series motor, as it would on a car, but brushes bearing on the rings will deliver alternating current. 500 volts on the d.c. end give about 300 volts on the a.c. end, the frequency being the number of revolutions per second of the armature. As the a.c. voltage lights three 110-volt lamps in series to normal brilliancy, its value is about 330 volts. This a.c. e.m.f. is applied to the primary coil of a homemade transformer $T1$, the secondary coil S which has six times as many turns as the primary p, so, theoretically, the a.c. test voltage would be $6 \times 330 = 1{,}980$ volts. The secondary voltage lights to full candle-power, eighteen 100-volt, 16 c-p. lamps L, L when test lines t, t', are held together; the a.c. test voltage available is, then, 1,800 volts. The manner of applying the high-voltage test lines is theoretically the same as that for low-voltage lines; practically, owing to the greater danger, extreme care must be taken to prevent personal contact with high-tension parts. The test points should be held on the ends of dry maple poles 5 ft. long; the testing space should be enclosed and but one man allowed within the enclosure when the motor is running.

To test the winding-to-shaft insulation of an armature, for example: Hook one test point over the armature shaft; close $K1$, then K, to start the test motor; pick up the second test point at the far end of its pole, touch test points t and t' together to see that the lamps light; then hold t to the commutator for 10 seconds; if the insulation is standard, the lamps will not light with it in circuit; but if defective, the high voltage will puncture it and lighting of the lamps will indicate that fact. Having made the test, hang up test point t, stop the motor, open $K1$ and remove point t'.

Too much stress cannot be laid on the importance of avoiding contact with any high-tension part; what might be trivial on a 500-volt circuit might here cause death. As the test is not used continuously, the transformer need not be made with the customary restrictions in regard to temperature and efficiency. An old ring armature can be converted to transformer use by dividing the winding into two parts such that one part has six times as many turns as the other; use the smaller section as the primary and the larger as the secondary of the test transformer. With a little care the outfit can be mounted to make a good appearance.

Note. In modern high-tension testing sets, instruments are used to indicate the presence of insulation faults and the alternating current from the same source is applied to indicating the presence of short-circuits in windings. These applications will be considered in detail in a pamphlet on *Railway Equipment Tests.*

MISCELLANEOUS TESTS.

ARMATURE TESTS.

Bar-to-Bar Tests.

50. The object of a bar-to-bar test is to see if all coils of an armature have approximately the same resistance; decided variation in its resistance means irregularity in the coil. It may have too many or too few turns, the wrong size of wire, a poor connection, an open or a short-circuit or the armature may be roasted in spots. To get the best results, the instruments must be low reading so that a small change in resistance will cause a large change in deflection; the voltage should be constant to avoid changes in deflection due to changes in voltage. Knowledge of the absolute resistance of the coils under test is an advantage, as variations in deflection can be easily checked. For absolute measurements, the instruments must be correct. Shop tests are usually limited to comparing the deflections of a voltmeter as its terminals are applied to adjacent bars all round the commutator, the current being maintained constant.

51. Directions. Connect the ammeter, a variable resistance and the armature in series, as in Fig. 43, the current being applied to the armature at the points usually occupied by brushes in operation—a brush holder and brushes can be used to advantage. Hold the voltmeter terminals on adjacent bars and adjust the current until the voltmeter gives a readable deflection. Then continuing to hold the test points in this same relation, slowly turn the armature and note the successive deflections as the volt lines make contact with the successive pairs of bars. Keep the current as constant as possible.

52. Remarks. In case of discrepancy in readings, they must be repeated, extra care being taken to keep the current constant. A high reading may mean too small a wire in the coil, too many

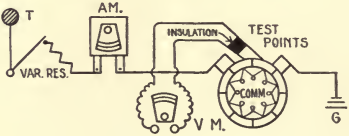

FIG. 43.

turns or a poor connection; a low reading may mean too large a wire, too few turns or a short-circuit in the coil or between the bars, to which the coil is connected. The cause of the discrepancy must be found by inspection.

53. An open-circuited coil will cause all readings except three to be twice what they should be for a given current, because the open-circuit leaves but one path through the armature, thereby doubling its resistance; as the tester keeps the current at the same value as if the two halves of the armature were in parallel, the drop in each coil is doubled because its normal current has been doubled. Two of the remaining deflections will be normal, corresponding to the two positions where the brushes make contact with the two bars that include the open-circuit and cut it out; the coil then spanned by the test points gets half the total current, as it should, and the deflection is normal. The third odd deflection is away too high, because the test points span the bars that include the open-circuit; the voltmeter is then subjected to the drop in half the coils in the armature, the coils on both sides of the test points acting as volt lines to connect the test-points to the brushes where the path of the current enters and leaves the good half of the armature.

54. If made of sufficient capacity so as not to foam, a water rheostat can be used for current regulation; as the water becomes heated and its resistance reduced, its effective length must be increased to keep the current constant. Where a storage battery or other source of constant voltage is used, no ammeter is required unless absolute resistances are wanted. If the test is prolonged, heating will increase the drop per coil, but as the change is small and gradual, it need not be misleading. It is desirable, on this account, to use the least current that will give a readable deflection and also the current must be kept within the maximum rating of the armature.

55. Current to Give a Certain Deflection. The instruments must not be subjected to currents exceeding their maximum rating. It is easy to keep within the range of an ammeter because its maximum graduation indicates its maximum rating and the variable resistance required can be calculated by rule 16, the line voltage being known. To keep within the maximum reading of a millivoltmeter, however, an approximate idea of the resistance of the armature coils under test must be had; then the current that will give a drop within the limit of the meter can be calculated by rule 9.

Example 42. In an armature bar to bar test, the maximum range of the ammeter available is 50 amperes. Neglecting the resistance of the armature, what extra resistance will keep the current under 50 amperes, the line voltage being 500?

Solution 42. By rule 16,

$$500 \div 50 = 10 \text{ ohms.} \quad \textit{Ans.}$$

Example 43. A millivoltmeter reading of 450 millivolts (0.450 volts) is to be used in a bar-to-bar test on an armature, each coil of which measures 0.012 ohm. What is the maximum current that can be used?

Solution 43. Here the resistance on which the meter reads the drop is 0.012 ohm and the current through it must be such that the drop may not exceed 0.450 volts. This current is, then, by rule 9, $0.450 \div .012 = 37.5$ amp. As 37.5 amperes is the maximum allowable current per coil, and as each coil gets but half the total current, the total current—that for which the variable resistance would be calculated—would be 2×37.5 amperes $= 75$ amperes. *Ans.*

Notes. This current would produce a drop within the limits of the voltmeter, but would exceed the rating of the armature in question. If there is no idea as to the resistance of an armature coil and no measuring means are available, it can be approximated by finding size and length of wire in a coil; multiply the length in feet by the resistance per foot as given in a wire table. Modern armatures may include 2 or more coils in a single slot; so care must be taken, when measuring, to measure only what will be included between two commutator bars after connecting the armature.

56. Current within the Armature Rating. Given the horse power of an armature, the maximum allowable testing current can be calculated by rule 23.

Rule 23. To get the maximum test current to be used on an armature of given horse power and voltage, *multiply the horse power rating by* 746 *and divide by the rated voltage.* The result will be full load current.

Example 44. A bar-to-bar test is to be made on a G. E. 1,000 armature. Assuming the rating to be 35 hp. at 500 volts, find the full load current.

Solution 44. By rule 23,

$35 \times 746 = 26{,}110$ and $26{,}110 \div 500 = 52$ amperes. *Ans.*

Example 45. The rating of a Westinghouse 12 A motor being 25 hp. at 500 volts, what would be the maximum current to use in a bar-to-bar test?

Solution 45. $25 \times 746 = 18{,}650$ and $18{,}650 \div 500 = 37.3$ amperes. *Ans.*

57. Where the horse power of a motor is not obtainable, the maximum current to be used in testing can be calculated approximately by rule 24:

Rule 24. To get the approximate safe testing current for a motor of unknown horse power, find the size of wire in the coils and get its cross section from a wire table; *divide the cross section in circular mils by* 450; the result will be the safe current for each wire.

Note. If the coil is wound with single wire, multiply the safe current per wire by 2; if wound with two wires in parallel, multiply by 4.

Example 46. A G. E. 1,000 armature is wound with single No. 9 B. & S. D. CC. copper wire. What is the safe testing current value?

Solution 46. Cross section No. $9 = 13{,}000$ circular mils (round numbers) and $13{,}000 \div 450 = 29$ and $29 \times 2 = 58$ amperes. *Ans.*

Note. The correct full-load current by rule 23, is 52 amperes; as the test current is made less than maximum permissible current, to avoid heat, this result is sufficiently close. On more modern armatures, the results of applying rule 24 will be more correct.

Example 47. A Westinghouse No. 68 armature is wound with No. 12 B. & S. wire; as each commutator ear has four leads in it, either the coils are wound two wires in parallel or the coils are connected two in parallel. In either case the current path from brush to brush consists of four No. 12 wires in parallel. What would be a safe test current?

Solution 47. Cross section No. $12 = 6{,}500$ cir. mils (round numbers) and $6{,}500 \div 450 \doteq 14.5$ and $14.5 \times 4 = 58$ amperes. *Ans.*

Note. The No. 68 is rated as a 40-hp. motor and rule 23 would give 60 amperes as full load current at 500 volts.

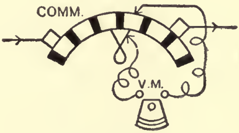

Fig. 44.

Lead-to-Bar Test.

58. Imperfect connections between leads and commutator are sometimes indicated by an eaten out appearance of parts of the commutator. The connections can be tested as indicated in Fig. 43, only instead of applying the test points to adjacent bars, one point is touched to a bar and the other to its connecting lead, as in Fig. 44. A deflection that is high as compared to the general run of deflections indicates an imperfect connection.

Telephone Tests.

59. Short-Circuit Test. A simple quick test for open and short-circuits in the armature can be made with a telephone receiver connected as in Fig. 45. Current is introduced into the armature as in Figs. 43, 44 and 45.

The source of current may be a couple of dry cells, a d.c. or a.c. lighting circuit. Where direct current is used, either one of the test points must be tapped intermittently to one of the bars

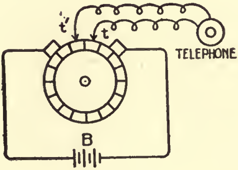

Fig. 45.

touched or an electric bell or buzzer must be included in the supply circuit, because unless the current is made to vary, the telephone diaphragm will be attracted once when the circuit is closed and will remain in that position until the circuit is opened; to give its characteristic sounds a telephone must be acted on by a varying current that alternately allows the receiver diaphragm to be attracted and released. Where an alternating current is available, no current interrupter is required.

60. With the test points applied to adjacent bars, the telephone receiver coil may be subjected to two influences: first, there is a p.d. in each armature coil, due to its resistance, as the current varies, this p.d. will also vary and thereby impress on the telephone coil the variable voltage required to produce the vibration of the diaphragm. The intensity of the vibration, hence of the sound given by the telephone, will depend on the p.d. to which the telephone coil is subjected and this on the resistance of the armature coil. Assuming an armature coil of normal resistance to give a telephone sound of normal intensity, an armature coil of greater or less resistance will give a sound of greater or less intensity; thus a short-circuited armature coil would produce little or no sound because it would have little or no resistance, hence little or no p.d. across it; an open-circuited armature coil would give a sound of disagreeable intensity, because the telephone would be subjected to the p.d. in the coils of half the armature; between these limits the intensity of sound depends on whether the fault increases or decreases the resistance of the armature coil and how much. If a direct current is used without an interrupter the action described is the only one that occurs and it would be possible to pass without detection, a coil of too few turns of too small a wire because of its resistance being just right. Second, where the supply is a.c. or d.c. with interrupter, a second effect, called the *auto-transformer effect*, obtains.

An alternating or pulsating current through the armature magnetizes and demagnetizes the core, thereby setting in motion, magnetic lines of force that cut the armature coils and generate in them voltages opposed to the supply voltage. An explanation of the transformer effects would be out of place here but it may be said that the telephone coil spanning the armature coil under test, creates a local circuit through which the back-voltage due to the moving lines of force can act to establish a secondary current that affects the telephone; any fault, such as too many turns in the armature coil, increases the current in the local circuit and the intensity of the sound; any fault such as too few turns in the armature coil, decreases the current in the local circuit and decreases the intensity of the sound. The difference in sound due to difference in the transformer action is sufficient to detect a coil of the correct resistance that may have too many or too few turns. As the two effects conspire to the same end, they cannot be separated nor can they confuse. The duty of the tester is simply to try every armature coil and investigate any that give abnormal intensity of sound. The alternating current test is however to be preferred to the test with the direct current.

61. Ground Test. Another useful application of the telephone is to locate the faulty bar or coil in a grounded armature, a ground on a ground-return circuit being a special case of short-circuit. A battery or d.c. lamp circuit with interrupter or an a.c. lamp circuit without any interrupter, is applied as in Fig. 46. Here S is the armature shaft and one of the armature coils is supposed to be grounded to it or the core through a fault at a. To make the test, one terminal of the 'phone is held to the shaft and the other touched around the commutator from bar to bar. Ordinarily the telephone will click because it is subjected to a p.d. represented by the drop in the armature coils that extend from the fault to the bar touched by the free test line t; however, as soon as the free

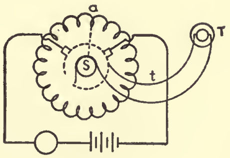

FIG. 46.

test line touches the bar to which the faulty coil connects, the click ceases or becomes a minimum, but increases in intensity if t is moved on beyond the faulty connection. When t is touched to the faulty bar, both test lines are connected to the shaft; both ends of the telephone being then at the same potential, it is subjected to no p.d., takes no current, hence emits no noise.

DIFFERENTIAL VOLTMETER TEST.

62. Where the test voltage is variable, a low reading differential voltmeter is well adapted to indicate differences in armature resistances. Fig. 47 indicates the connections. Current is passed as in the bar-to-bar test; one coil of the differential voltmeter is permanently connected to one of the armature coils or to a standard coil of the same resistance so connected, as to get the same current hence the same drop. The other voltmeter coil is connected to test points that are moved from bar to bar. Assuming the resistances of all armature coils to be the same as that of the standard, on passing the test lines from bar to bar the volt-

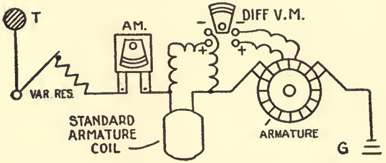

FIG. 47.

meter needle will stay at 0, because the equal drops oppose each other in their action on the needle. If the resistance of a coil is above or below normal, however, the drop in it will be more or less than that in the standard, the current in both being the same, and the excess will move the needle to one side or the other of 0 and by an amount equal to the voltage by which the drop on one coil exceeds that on the other. If the test coil resistance exceeds that of the standard, the needle will deflect to the right, say; but if the standard resistance exceeds that of the test coil, the needle will deflect to the left. The cause of any marked discrepancy must be located by inspection.

TRANSFORMER TEST.

63. A modern method of testing finished, connected armatures for short-circuits, is with an a.c. transformer connected as in Fig. 48. Here *A* is a 50-hp. railway motor pole piece, slotted on the concave side so as to take about 200 turns of No. 10 B. & S. magnet wire. Angle iron plates *a* and *b*

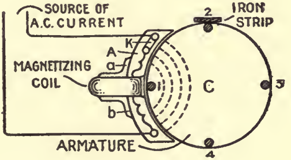

FIG. 48.

support the wire in winding and protect it in operation. The winding has terminals and a small switch *K* mounted on the shoe so that the test current can be conveniently interrupted. The shoe is supported on legs so that it can be leaned against the armature, or has a bail with which to hang it on to a hoist so that it can be raised or lowered. In any case the shoe is made to engage the core of the armature to be tested; the a.c. lines are then connected to the binding-posts and *K* closed. The shoe and coil and the armature core normally act as a choke coil and the shoe winding takes but little current. Each alternation of the current causes magnetic lines of force to move and cut all armature conductors lying between the test shoe horns. As each slot holds conductors belonging to both halves of the armature and as both halves have the same number of turns and as the current in them is in opposite directions, so long as the armature has no short-circuited coil, the tendency of the magnetic lines to produce current in one half of the winding, is balanced by the equal but opposite tendency to produce current in the other half, the result being zero current. A short-circuit in a coil or cross between the bars to which it connects, creates a local circuit in one half of the winding but not in the other, thereby destroying the balance; so that the moving lines of force cause a current as soon as any conductor involved in the fault lies between the two test shoe horns. On a railway motor armature of the usual type, a short-circuit will affect four armature conductors because each pair of bars contains leads from two coils the legs of which lie in four equidistant slots on the core. Any demonstration at a given slot 1 will be manifest at the almost diametrically opposite slot 3 and at slots 2 and 4, Fig. 48, half way between 1 and 3. Current in the local circuit established by the fault sends out lines of force that react on the lines due to the test shoe coil; the result of this reaction is to weaken the magnetism of the shoe, decrease its choking effect and admit a larger current. One method of indicating a short-circuit is to place in series with the shoe coil an ammeter the reading of which will be above normal when a short-circuit exists. As the tester soon becomes familiar with the current taken under normal conditions, the ammeter reading indicates at once the existence of abnormal conditions.

A shoe the horns of which are sufficiently far apart to send the magnetic lines through the core in the same relation as would the pole pieces in which the armature operates, gives the widest range of effect, but such a shoe is comparatively heavy.

64. The more usual method of indicating a short-circuit is with a thin iron strip held in the hand and passed around the core as follows: Turn on the current and hold the vibrator to the core at points about at right angles to the point midway between the shoe horns; then stop the current, rotate the armature a little, start the current again and again apply the vibrator; repeat these operations until all slots have been tested. The instant a conductor involved in the fault comes under the vibrator, the vibrator vibrates in a characteristic manner.

Note. When there is alternating-current in the local circuit due to the fault, the coils composing the local circuit produce an alternating field which causes the iron strip to vibrate whenever it is over a slot containing a conductor involved in the local circuit.

LATHE TEST.

65. Where an alternating current is not available for a transformer test, an equivalent test can be made with a test shoe excited by direct current. In this case it is best that the shoe horns span the core as do the poles of the motor in which the armature operates. The armature is swung in a lathe and the test shoe run up near to it; provision being made to prevent the magnetism from drawing the shoe actually against the core; the shoe is excited, the lathe started and the vibrator held near the core. A short-circuit, howsoever slight, will cause the vibrator to act in an unmistakable manner. The magnet can be wound with fine wire and the current held to a safe value by incandescent lamps in series, or it can be wound with coarse wire and a heavy current used and regulated with a water rheostat.

SPINNING TEST.

66. The spinning test consists in running the motor at full line voltage before or after it has been hung on the truck. This test shows the condition of the bearings and shaft, the set of the brushes, open and short-circuits and the direction of rotation for given connections. For this test, connect one field terminal through resistance to trolley; connect one of the brushholders to ground; connect the remaining field terminal and brushholder together. Unless the motor frame rests on a grounded part, a ground connection must be run from the frame to the track rail or one brush-holder must be connected to the motor frame, otherwise the presence of a fault-ground will cause no indication.

67. Bearings and Shaft. The armature bearing caps are tightened before the spin; if the bearings heat they are removed and scraped. A sprung shaft will wobble on the end. An unbalanced core will cause excessive vibration but the shaft ends will not wobble. An eccentric commutator will cause the brushes to draw in and out of the holders as the armature rotates. A high or low bar or flat commutator will make the brushes chatter. End play is tested by pushing on both ends of the shaft and noting the travel: the end play should not exceed $\frac{1}{8}$ inch.

68. Brush Set. Radial brushes should rest flat on the commutator; on brush holders of the independent type an even bearing across the brush contact indicates correct brush set. On holders of the yoke type, however, the motor should be loaded with a brake to see that the brushes do not spark. In either case, if one or both brushes bear on the heel or toe, they need adjustment. The distance between the inside edges of the brushes should be one quarter of the commutator circumference less the width of one brush.

69. Open and Short Circuit. An open circuit in the field winding will prevent starting. An armature open-circuit will cause a rotating spark. An armature short-circuit will cause jerky rotation and a strip of iron held near the head of the armature will pulsate in a characteristic manner.

70. Grounds. To insure that the test shall indicate field as well as armature grounds, the field winding must be connected next to the trolley as in Fig. 49. With the armature winding next to the trolley, its counter e.m.f. consumes most of the line voltage, leaving insufficient e.m.f. to cause a demonstration even if a field coil is grounded. Failure to observe this precaution will allow a

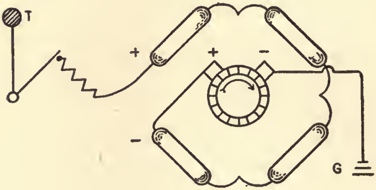

Fig. 49.

grounded field coil to pass the spinning test without being detected.

71. Connections. By observing a fixed rule in connecting the motors, then noting the direction of rotation in each case, the tester can detect irregularities in rotation; thus, in the case of a so-called left-hand armature or in case the field coils as a whole are connected in the wrong relation to the armature winding, rotation will be opposite to the usual direction. If the coils are regular in winding and connection, the armature must be irregular. In all modern controllers, the + armature connections are marked with *A* and the – armature connections with *A A*, and the + field connections with *F* and the – field connections with *E*, a number placed after the letters indicating to which motor the connections belong. Thus *A*1 is the + armature connection of motor No. 1 and *E*4, the – field connection of motor No. 4, and so on. If the spinning test shows that the motor armature turns clockwise when viewed from the commutator end and the left hand brushholder and top field terminals are made +, then when the motor is on a car it follows that to have the armature turn clockwise the left hand brushholder must be made *A* and the top field terminal, *F*, the remaining brushholder being *A A* and the bottom field terminal, *E*. Knowing the direction of rotation of the motor for given connections, the manner of connecting the motor terminals to the tagged car-wires is fixed irrespective of the position of the motor on the truck. As the armature and car wheels are geared together, the direction of movement of the car will be opposite to that of the top of the armature.

FIELD CONNECTION TEST.

72. Adjacent field coils in a motor should produce poles of opposite polarity; a nail can be used to find out if they do or not. Open the motor, remove the armature, close the motor and establish a safe current through the field coils connected in series. Holding the nail between the thumb and forefinger, present the point to any pole piece and move the nail toward either adjacent pole piece; if the coils are correctly connected, the nail will persevere in the position of *T*, Fig. 50, and effort will be required to make it take any other general position in its passage from one pole to the next one. This is because it lies in the general direction of the magnetic lines of force running from the *N* to the *S* poles, and is unstable in any other position. Also on touching the nail to the pole pieces

Fig. 50.

Fig. 51.

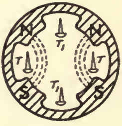

Fig. 52.

and pulling it away, the pull on all will be about the same. Fig. 51 shows the general path of the magnetic lines when one field coil is connected wrongly, making three *S* poles and one *N* pole; here on either side of the wrongly connected coil no effort will be required to turn the nail to position *T*1, the nail seeming to have no well directed tendency. Also the pole due to the wrongly connected coil will exert less pull than the others. Fig. 52 shows the stable positions of the nail when two coils are wrongly connected. On every pole, the nail will act normally on one side but will have no directed tendency on the other; also one horn of each pole piece will be much stronger than the other. In this case, to right matters, reverse the connections of the coils on the two pole pieces between which the nail action is normal. Where a motor has but two field coils, as in the case of the G. E. 800, no test is needed, because if one coil is reversed the armature is unable to start without excessive current.

With practice the nail test can be made without removing the armature. To a beginner the poles induced in the armature core by the pole pieces is apt to be confusing. This simple test is applicable to any kind of machine of any number of poles.

LOCATING CHARGED AND GROUNDED CAR PARTS.

73. Car parts normally alive when the motor circuit is active may become "grounded" and cause irregular action; similarly, parts normally grounded may become dangerous as the result of becoming "charged." Thus the starting coil resistance metal is alive in operation but is supposed to be thoroughly insulated from the ground. A "dead ground" on the starting coil will prevent a car from starting as the current short-circuits to ground without reaching the motors; a partial ground, however, is even more to be avoided as it may result in charging some part on which a passenger must step. Controller frames are well grounded so that they may not become charged from defective internal insulation and shock a person touching them and grounded parts at the same time.

74. A charged or grounded condition can be detected and its cause exactly located with a voltmeter. To test for a grounded part, connect one side of the voltmeter to trolley and use a free test line from the other side to explore by contact, the suspected area and its connections after having disconnected all intentional ground connections to that area. The instant the test point touches a grounded part, the voltmeter needle will deflect, because current from the trolley has its path through the meter to and through the fault, to ground. To test for charged parts, connect one side of the voltmeter to ground and explore the suspected area with a free test line from the other side of the meter. Contact with a live part will cause a deflection, because the live part becomes grounded through the voltmeter.

Rule 25. To test for a ground with a voltmeter, connect one end of the meter to trolley and explore with the other. To test for live parts with a voltmeter, ground one side of the meter and explore with the other. Where several connected devices cause a deflection, disconnect them and test each separately.

Example 48. On a certain car in damp weather passengers stepping on to the car platform from inside, get a shock. Find a cause with a voltmeter.

Solution 48. On grounding one side of a 500-volt voltmeter and exploring with the other, contact with a resistance hanger bolt extending through the car floor gave a deflection of 475 volts. Inspection showed defective insulation between the resistance metal and frame, so that as soon as the controller was put on an operating notch, thereby charging the resistance metal, the frame, hanger and supporting bolts became charged and a person stepping immediately over the bolt head and on to the damp platform simultaneously, formed a circuit through which the electric shock could pass.

Note. Had the voltmeter shown full line deflection it would have meant a "dead ground" and the car could not have been started.

Example 49. On a certain car the conductor got a shock every time he "rang up" a fare. How could the cause of this condition be located?

Solution 49. As the register rigging was confined to the upper parts and ends inside of the car, the bulkhead wiring was suspected. With the pole on and both breakers closed, one side of a voltmeter was grounded and the other side touched to the register rod; full line deflection indicated actual contact with a trolley part. On disconnecting the register rod and lifting the register from its hangers, connected only when the register was in place, only one of the hangers gave appreciable deflection; removal of one of the hanger screws did away with all deflection. Inspection showed the screw to have penetrated the insulation of the bulkhead trolley-wire, thereby charging the register pulls through the rigging.

Example 50. On a certain stove heated car equipped with independent air brake, contact with the stove caused a shock even on a dry day. Why?

Solution 50. On grounding one side of the voltmeter and touching the other side to the stove, there was no deflection, showing the stove to be free from charge. On connecting one side of the meter to trolley and the other to the stove, full line deflection showed the stove to be well grounded. As the stove was the ground end of the trouble circuit the " live " end had to be sought elsewhere. On grounding one side of the meter and exploring the area around the stove, a charged bolt head was found. The bolt passed through a piece of tin under the car and though no longer used was in contact with a hanger of the governor pipe. On this equipment the compressor and all of the governor parts were insulated from all ground parts with an insulation joint, to lessen the chances of grounds. One of the compressor armature terminals was grounded to the frame, thereby charging the frame, governor pipe, hanger, tin, bolt and the area around the bolt head, so that a person standing on the bolt head and touching the stove was directly across the 500-volt circuit.

Example 51. Another car gave the same symptoms only the shock was less severe.

Solution 51. On grounding one side of the voltmeter and touching the other side to the stove, full line deflection showed the stove to be charged An uninsulated two-way connector that connected the governor to trolley lay on an angle iron that fastened the stove base to the floor. The stove happened not to be grounded.

Example 52. On a certain flat car, the trolley wire from the trolley base to the circuit breaker was run in an iron pipe. A person standing on the cement floor and touching the pipe, got a shock. Why?

Solution 52. Had the pipe been grounded it would have given no shock; on grounding one side of the voltmeter and touching the other side to the pipe, the deflection was 450 on a line voltage of 500. On disconnecting the trunk wire from the base and testing insulation from wire to pipe (see Art. 40) no deflection obtained; on reconnecting the trunk wire to the base and testing the insulation of wire to pipe, a deflection of 450 again obtained, indicating the defect to be in the base. Next the pipe was pulled loose from the base and the insulation from wire to pipe tested; it was perfect. On replacing the pipe, grounding it through a lamp circuit, connecting one side of the voltmeter to trolley and exploring the stretch of wood between the base and the pipe any deflection from 0 to 425 could be gotten. This showed that the defective insulation was the oak board on which the base was mounted and to which the pipe was cleated. A maple board did away with all leakage.

Note. Oak contains acid and cannot be depended on as an insulator.

GENERAL TESTING PRECAUTIONS.

75. Correct results require either that the instruments be correct or that their error be exactly known; the condition of an instrument can be determined by comparing its readings with those of another known to be correct. If the condition of an instrument is unknown, make the test, check the instrument with a standard afterward and make necessary corrections in the calculations. To avoid error in reading, be certain that the needle is just over its own reflection in the mirror.

Portable instruments should not be put in their boxes upside-down; in the box the needle should hang down. In use it is generally best that the instrument rest level. In presence of vibration, as on a car, hold the instruments in a box partially filled with waste.

Never subject an ammeter to excessive current nor a voltmeter to excessive voltage; in all cases get an approximate idea of the maximum value to be indicated and if excessive, use a shunt or a multiplier as the case may be. Always connect the + side of an instrument to the + side of the circuit. The + side of the instrument is generally indicated by a + mark and the + side of the circuit can be ascertained by test or inquiry. Where a meter has extra connecting posts unfamiliar to the tester, consult someone who knows about them; the method of trial may here cause trouble.

In testing with an ammeter or voltmeter or both, use instruments the rating of which is adapted to the quantities to be indicated; to illustrate, don't use a 500-volt voltmeter to read a drop of 3 volts, nor a 150-amp. ammeter to indicate the current of a lamp circuit, because since each division has a high value an error in reading will have a correspondingly high value; on the other hand don't connect a millivoltmeter across a high drop nor use a milliammeter to read a large current. Never try to use an ammeter as a voltmeter as it will certainly cause trouble for operator and instrument.

On variable voltage, repeat readings and sets of readings until it is certain that they are correct; especially valuable are repeated readings where simultaneous ammeter and voltmeter readings are to be taken. In comparing resistances care must be taken that they are at the same temperature, because the resistance of the common conductors, except carbon and water, increase with temperature. In such tests use the minimum allowable current and dispose the resistances so that they will heat at equal rates. To check results it is well to repeat whole tests at different current and voltage values and then compare the results of calculation.

Never close a switch unless certain of existing conditions; but once having decided to close it, close it with a will so that should conditions be such as to produce a short-circuit, the tester will not be burned. Always include in circuit, a fuse, circuit breaker or other safety device, to protect the ammeter in case of short-circuit.

HELP TO THE INJURED.

Reviving Shocked Persons.

76. The following directions for reviving persons from the effects of electric shock (or apparent drowning) are due in substance to Augustin Goelet, M.D., and are adapted from the *Electrical World and Engineer Supplement* of September 6, 1902. In all cases the operations described are to be begun without delay and continued until the arrival of a physician.

I. Remove the body from the live conductor. If in midair, poke it loose with a wooden pole and catch it in a blanket held at the four corners, unless there are present facilities and persons qualified to safely use more refined methods. If on the surface use a dry stick or protect the hands with dry clothing.

II. Turn the body upon the back, loosen the clothing around the neck and chest and place a rolled-up coat under the shoulders to throw the head back and mouth open. Kneeling at the victim's head, seize both arms and draw them to full length and almost together over the head, as in Fig. 53, to expand the chest and open the windpipe; hold this position for two or three seconds; next carry the arms down to the sides, Fig. 54, showing the half-way position, and front of the chest, firmly compressing the chest walls, as indicated in Fig. 55, to expel the air from the lungs. These successive operations of drawing the arms back over the head almost together, and then

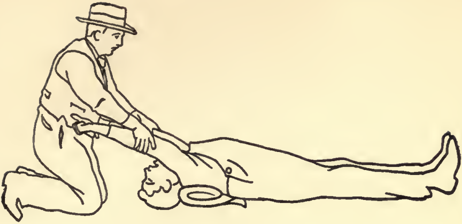

FIG. 53.

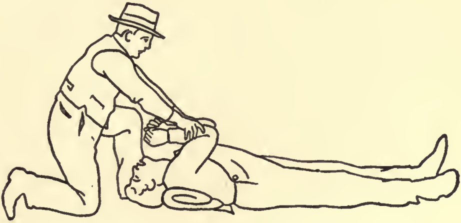

FIG. 54.

FIG. 55.

bending them as in Fig. 54, and finally compressing them on the chest side walls, as in Fig. 55, must be repeated from sixteen to eighteen times per minute and continued ceaselessly for at least an hour, or until breathing is normal. (This method has been known to resuscitate patients who had been under water several hours.)

III. While artificial breathing is being thus conducted a second person should grasp the victim's tongue with a handkerchief (forcing the teeth apart with a knife or piece of wood if necessary and pull the tongue out in step with the stretching back of the arms, and allowing it to recede into the mouth when the chest is compressed.

IV. Dashing cold water in the face, brisk rubbing of the spine with ice, or alternate heating and cooling of the region over the heart, all tend to produce a gasp and thereby start breathing, which should then be continued artificially until it becomes natural. It is both useless and unwise to try to revive the patient by pouring stimulants down the throat. In all cases send for a physician.

Relieving Burns.

77. The simplest and most satisfactory relief for an electric burn is to immerse the effected part in a mixture of linseed oil and soda, and to keep it there until all soreness is removed. In dangerous localities, where numbers of men are employed, a barrel of this mixture should be kept on hand. In case of severe body burns the patient may stand in the barrel. In all cases it is best to consult a physician.

Questions

1. How is an ammeter connected to indicate current in a conductor?

2. Does it make a difference which connecting post is made +?

3. Does the ammeter resistance appreciably affect the test current?

4. Can large currents be indicated on two ammeters in parallel?

5. What is requisite for two meters to read their joint rating?

6. In what two ways can the sharing of current between them be regulated?

7. Why are these devices objectionable for permanent work?

8. What is meant by *shunting* an ammeter? What is the *constant*?

9. How can a shunt be adjusted with a second ammeter?

10. How can a shunt be adjusted without a second ammeter?

11. What is the usual objection to a fractional constant?

12. When is a fractional constant permissible?

13. If the shunt heats, will the constant change?

14. Will a shunt adjusted for one meter do for another?

15. Give the rule for determining the constant of a certain adjustment?

13. If the shunt heats, will the constant change?

14. Will a shunt adjusted for one meter do for another?

15. Give the rule for determining the constant of a given adjustment?

16. Can current be measured with a voltmeter and known resistance?

17. Give the connections and the rule to be applied.

18. How can the current taken by a car be approximately ascertained?

19. Give the rule for measuring current with a wattmeter.

20. On what two factors do wattmeter indications depend?

21. If volts be multiplied by amperes, what unit results?

22. If watts be divided by volts, what unit results?

23. If watts be divided by amperes, what unit results?

24. Watt-hour meter records are usually expressed in what units?

25. How can the watt rate be gotten from the watt-hour record?

26. Does a watt-hour meter give information as to volts and amperes?

27. How can average volts or amperes during the time of a record be gotten?

28. How is voltage or potential drop measured with a voltmeter?

32. What would be the objection to a low resistance voltmeter?

33. Why does a voltmeter in series with other resistances take almost the entire line voltage across its own terminals?

34. What is the effect of connecting a resistance in parallel with another?

35. Why does not a voltmeter do this to an objectionable degree?

36. Can high voltages be indicated on two voltmeters in series?

37. Will two meters so connected necessarily read the sum of their ratings? What condition is required for them to do so?

38. In connecting two voltmeters in series, how are the posts connected?

39. How can the maximum voltage readable on two meters in series be determined? What is meant by a voltmeter *multiplier*?

40. What is meant by the constant of the voltmeter and multiplier?

41. How can the constant of a given pair be calculated?

42. How can it be determined experimentally?

43. Give connections for experimental determination of the constant.

44. About what is the resistance of a 600-volt voltmeter? 500-volt voltmeter?

45. How can the multiplier resistance required to increase the range of a given voltmeter a certain amount be calculated?

46. What is the approximate resistance of a 16-c-p., 110-volt lamp?

47. Can incandescent lamps in series be used as a multiplier?

48. Can p.d. be measured with an ammeter and a known resistance?

49. Give the connections and the rule to be applied to do so.

50. Is it generally practicable to vary the voltage of a supply dynamo?

51. What is the common method of lowering the voltage acting on a device?

52. How does voltage applied to a circuit distribute itself?

53. Can storage cells be used to vary test voltages?

54. Does the voltage of a storage battery depend on the number of cells in series?

55. Why are storage cells not more used in regulating test voltages?

56. What is meant by *proportion lines*? Sketch their connections.

57. What is the advantage of having the resistance across the line composed of similar units? Name a good practical form of resistance unit.

58. How can the voltage acting on the meter be then calculated?

59. Can the voltage be first explored with a voltmeter?

60. In what field are proportion lines especially useful?

61. Can proportion lines be used for adjusting a voltmeter and multiplier from a voltage exceeding the maximum rating of the voltmeter?

62. Will the adjustment thus made on low voltage do for all voltages?

63. Can voltages be measured approximately with incandescent lamps in series? Give the connections and method of making them.

64. How is the total voltage acting calculated from the lamp indication?

65. Is the method applicable to alternating-current (a.c.) circuits?

66. Will low-voltage lamps give closer results than high-voltage lamps?

67. What is meant by *resistance* as applied to electric circuits?

68. Do insulators offer great resistance? Do conductors?

69. Does conductor resistance depend on length? Size? Material?

70. When are conductors said to be connected in *series*?

71. When are conductors said to be connected in *parallel*?

72. When are conductors said to be connected in *series-parallel*?

73. How may the resistance of conductors in series be calculated?

74. Is the resistance of two conductors in parallel less than that of either alone? What is meant by *parallel resistance* of conductors?

75. What is the approximate resistance of a 32-c-p., 110-volt lamp?

76. What would be the resistance of five such lamps in series?

77. Are the lamps on a single car-lamp circuit in series or in parallel?

78. Give rule for calculating parallel resistance of two like conductors.

79. Give rule for calculating parallel resistance of any two conductors.

80. Give rule for calculating resistance of any number of like or unlike conductors in parallel and calculate for 1, 2, 3 and 4 ohms?

81 Give rule for calculating the resistance to be connected in parallel with a certain conductor to make their parallel resistance of a certain value.

82. What resistance must be connected in parallel with a conductor measuring 10 ohms for their parallel resistance to be 7 ohms?

83. Give and apply the rule for calculating the resistance to be connected in parallel with a number of existing parallel conductors to make their final parallel resistance have a certain value.

84. Is this rule useful in designing parallel starting coils for cars?

85. What advantage has such a starting coil over the usual series type?

86. Can resistances be measured with a voltmeter and ammeter?

87. Give the connections and rule to be applied.

88. Give the approximate resistance used on a 20-ton electric car.

89. Give connections and method for measuring heater resistances.

90. Can resistance be measured with voltmeter and known resistance?

91. Give connections and rules to be applied in this measurement.

92. Why is it important to repeat the voltmeter readings?

93. How can the resistance of railway motors field coils be tested.

94. Will this test reveal the condition of the field coils?

95. What indication suggests that the coils be opened and inspected?

96. In testing field coils is it customary to work out resistances?

97. How can the approximate resistance of wire be gotten from a wire table?

98. Does the condition of the car equipment affect its resistance?

99. Does resistance affect the line voltage lost in the equipment?

100. Can resistance be measured with an ammeter and a known resistance?

101. Is this a method of great accuracy? If not, why not?

102. Give the connections and the rule to be applied in the test.

103. Why is it important to get both ammeter readings at same voltage?

104. Why are simultaneous readings on a railway circuit hard to get?

105. Give the main construction points of a *differential voltmeter.*

106. Do variations in line voltage affect both deflecting coils?

107. Must the pairs of posts be so connected as to oppose each other?

108. Give the method of measuring starting coils differentially.

109. About what should be the rating of the meter for this work?

110. Is it necessary to keep the current below a certain value? Why?

111. At about what value is the current regulated? By what means?

112. Describe a test on a car resistance coil in place.

113. Why is the car brake applied?

114. What would be the advantage of a scale under the standard resistance?

115. Why is the standard resistance made greater than that on the cars?

116. How is a *plug* bridge distinguished from a *slide wire* bridge?

117. Why are plug bridges not adapted to shop work?

118. Describe a homemade slide wire bridge.

119. Why should the battery key be pressed before the galvanometer key?

120. What portion of the wire gives the most accurate balance point?

121. When is a bridge said to be balanced?

122. How is the balance effected? Can a telephone be used instead of a galvanometer; in such cases why must the stylus be tapped on the wire?

123. Where the exact balance point is undecided, what is done?

124. What is an *ohmmeter*? Sketch the Sage ohmmeter connections.

125. Why is an ohmmeter called *direct reading*?

126. Can a slide wire bridge be made direct reading? If so, how?

127. Describe the method of making a measurement on the Sage ohmmeter.

128. Give the rule applied to slide wire bridge resistance measurements.

129. In how many ways can insulation resistance be tested? Name them.

130. What is the objection to the bridge, bell and magneto methods.

131. For what duty are these devices better adapted?

132. How great a voltage should be used in insulation testing?

133. Is a thin air-gap perfect insulation against low voltages?

134. Is a thin air-gap perfect insulation against the higher voltages?

135. Does high voltage subject insulation to breaking down stresses?

136. Are such stresses not possibly injurious to the insulation?

137. Where an actual arc is started, can the insulation be carbonized?

138. What voltage should railway motor insulation be able to stand?

139. If unable to stand 2000 volts, what is liable to happen?

140. Should other insulation pass a spark before the lightning arrester?

141. Can insulation resistance be measured with a voltmeter?

142. On what important fact is such a measurement based?

143. State the general connections for making the test.

144. Give the rule for measuring insulation with a voltmeter.

145. Does failure of the meter to deflect indicate perfect insulation?

146. Is there any such thing as perfect insulation?

147. What is meant by the *insulation drop* or *insulation deflection*?

148. Are the meter and insulation drops related as are their resistances?

149. Give the second and more common rule used in this measurement?

150. Give the actual method of testing armature insulation.

151. On a ground return system what precaution must be taken for ground?

152. Is it not important first to be sure that the test circuit is O.K.?

153. What is meant by a *megohm*?

154. Describe insulation test on an armature installed in a car.

155. To what may low armature insulation be due?

156. Is it important that car controller frames be well grounded?

157. If not grounded, what effect is poor controller inside insulation apt to have?

158. What is the principle of locating weak insulation with a voltmeter?

159. Can parts individually well insulated show low when connected?

160. How can commutator insulation from bar to shell be tested?

161. How can commutator insulation from bar to bar be tested?

162. By what means can the bars become short-circuited together?

163. Will baking new or damp armatures in an oven improve the insulation?

164. On a slotted conduit system what precaution must be taken in connecting the ground test line?

165. In shop work is the insulation resistance always actually expressed?

166. Give rule for finding voltmeter deflection corresponding to a certain adopted insulation standard.

167. Can indcandescent lamps be used to indicate condition of insulation?

168. Give the connections and general application of the method.

169. On what does the number of lamps in series depend?

170. Is the lamp test as severe as would be direct line voltage?

171. In case of zero insulation how do the lamps act?

172. Is their degree of brilliancy any indication of state of insulation?

173. In shop practice how are the lamps and test lines mounted?

174. When must a ground test line *t′* be run as in Fig. 33?

175. What is the result if this line is omitted?

176. In using two test lines *t* and *t′* what precaution must be observed?

177. If not observed are results apt to be misleading?

178. What is the objection to testing from bar to bar with a lamp test?

179. Is a low voltage to be recommended in this connection?

180. Why is an alternating voltage to be preferred for this work?

181. Why are bell circuits poorly adapted to insulation testing?

182. To what are their reliable indications really limited?

183. For what class of work are they most used?

184. How is a bell outfit gotten up for shop use?

185. Give the method of applying the bell test.

186. Is the voltage sufficient to ring the bell through fine wire magnets?

187. This being the case, is an indication of open-circuit always reliable?

188. What is a magneto machine? What kind of current does it generate?

189. About what voltage do hand turned magnetos generate?

190. Can this be increased by belting the machine to shop shafting?

191. Is not the machine then very satisfactory for insulation testing?

192. What misleading result does the machine give at times?

193. To what is this misleading indication due?

194. On what electric railway devices is it liable to obtain?

195. What is meant by high voltage insulation tests?

196. Describe a homemade outfit for making such tests.

197. How can the high voltage be indicated without instruments?

198. Give the method of conducting the test with such an outfit.

199. In what regard must extreme care be taken?

200. How can a satisfactory transformer be homemade?

201. What is the object of a bar to bar test on an armature?

202. What is the common method of conducting such a test?

203. What does a variation in coil resistance indicate?

204. Name some of the irregularities that a coil may have.

205. Is it customary to measure the absolute resistance of the coils?

206. Give a good device for introducing test current to the armature.

207. Is it important to keep the current the same for two readings?

208. To what may an abnormally high deflection be due?

209. To what may an abnormally low deflection be due?

210. How must the cause of discrepancy be located?

211. In case of an open-circuited coil, what is the indication?

212. Can water resistance be used to regulate the current?

213. How is the current affected by the heating of the water?

214. Where constant voltage is available is an ammeter needed?

215. If the test is prolonged will the standard deflection increase?

216. Why will not this increase be misleading to the tester?

217. Is it desirable to use the least current that will give a satisfactory deflection?

218. Must the rating of the armature and instruments be considered?

219. Must the variable resistance be selected to suit the test current?

220. Give the rule for calculating the proper regulating resistance.

221. Give the rule for finding the current such that the drop on a coil will not exceed the capacity of the voltmeter used.

222. How can the approximate coil resistance be found without testing?

223. How can maximum armature current be calculated from its horse power?

224. How can it be calculated from the size of the wire in the coil?

225. Must the method of connecting the coils be considered?

226. Why is the total current taken as twice that allowed for the wire?

227. Describe the lead to bar test and state its object.

228. What conditions will cause high deflections?

229. What appearance may suggest the necessity of this test?

230. Describe the telephone method of testing an armature.

231. What source of current is generally used?

232. Of what advantage is an alternating current or a current interrupter?

233. What two influences act on the telephone coil?

234. What is the indication of an open circuited coil?

235. How is a short circuited coil indicated?

236. Can a differential voltmeter be applied to this armature test?

237. Give the method and general connections of the test.

238. Has the direction of the voltmeter deflection any significance?

239. What is the modern method of testing for armature winding faults?

240. Describe the construction of the test shoe.

241. What kind of e.m.f. is required for the transformer test?

242. State briefly the theory of the test.

243. Has each slot conductors belonging to both halves of the armature?

244. Primarily may the test shoe coil be considered as a choke coil?

245. Does a short circuit increase the choke coil current?

246. Can this increase be made to indicate the existence of the fault?

247. What is the more usual method of indicating the existence of fault?

248. In how many slots will the vibrator show maximum vibration?

249. What is the objection to an air gap between the shoe and armature?

250. What would be the best shoe construction to use?

251. Would such construction be consistent with demands for lightness?

252. Describe a lathe test equivalent to the a.c. transformer test.

253. Can the shoe be wound with either coarse or fine wire?

254. What is meant by the *spinning test*?

255. Name some of the conditions revealed by it.

256. Give a sketch of the connections used.

257. What is the advantage of making a field terminal the trolley end?

258. Why should the armature bearing caps be screwed down tight?

259. What is the indication of an eccentric commutator? A bent shaft?

260. What is the symptom of an unbalanced core? High bar? End play?

261. How should radial brushes rest on the commutator?

262. What does heel or toe contact indicate?

263. How many bars should be included between inside brush edges?

264. Why do grounded field coils sometimes pass the truck spinning test?

265. State the advantage of using standard connections in the test.

266. Either of what two faults can cause reverse rotation?

267. What polarity have the single A's in modern controllers?

268. Knowing this, is the information given by the spinning test of any use in deciding how to connect motors to turn so as to move a car in a certain direction?

269. How are the directions of the car and the top of the armature related?

270. What should be the relative polarity of motor poles?

271. How can this polarity be tested with a nail?

272. What is the advantage of removing the armature in the test?

273. What causes the nail to take certain set positions?

274. Is the test applicable to motors of any number of poles?

275. Is a car starting coil alive during normal operation?

276. What happens if it becomes dead grounded?

277. Why is it customary to ground controller frames?

278. What may happen if they are poorly grounded?

279. Can charged or grounded conductors be located with a voltmeter?

280. Give the rule for locating a ground with a voltmeter.

281. Give the rule for locating a charged part with a voltmeter.

282. Name some conditions under which passengers get shocked.

283. Name a condition likely to shock the conductor.

284. In testing for ground, what does a full line deflection mean?

285. In testing for a charged part what does such a deflection mean?

286. Why are air compressors and governors insulated from ground?

287. Can a coal stove become charged as the

result of contact with a live conductor. How would such a charge be located?

288. Under what other condition can the stove cause a shock?

289. May oak be called a good insulator against trolley voltage?

290. How can the correctness of instruments be checked?

291. What precautions must be taken in reading a deflection?

292. How should instruments be shielded from excessive vibrations?

293. Should instruments be selected to suit the work in hand?

294. What is meant by artificial respiration?

296. Describe the artificial respiration method of reviving shocked persons. Give a simple treatment for electric burns.

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